SUSY Searches at CMS

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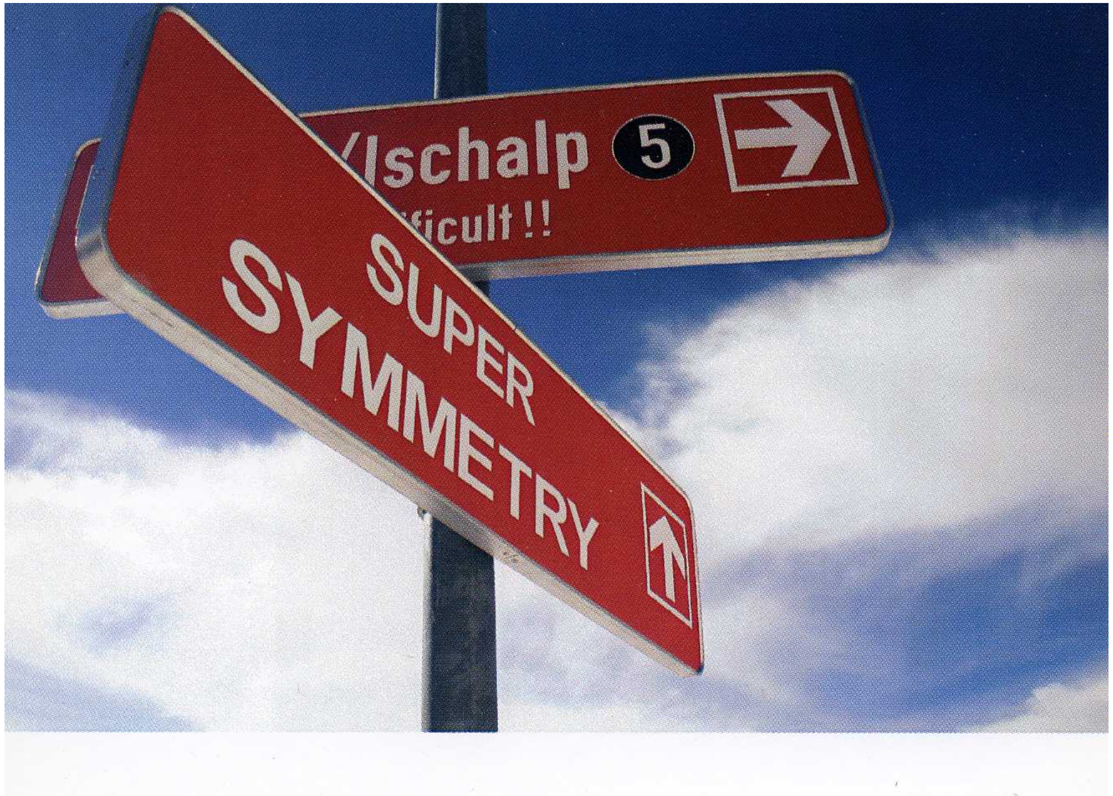
for the CMS Collaboration

SUSY 2011
Fermilab/Chicago

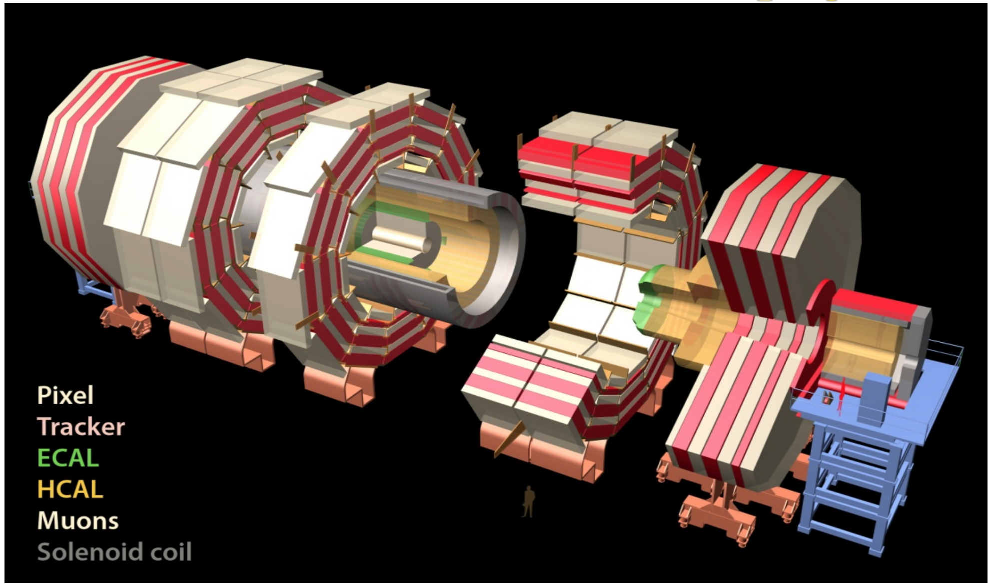
Outline

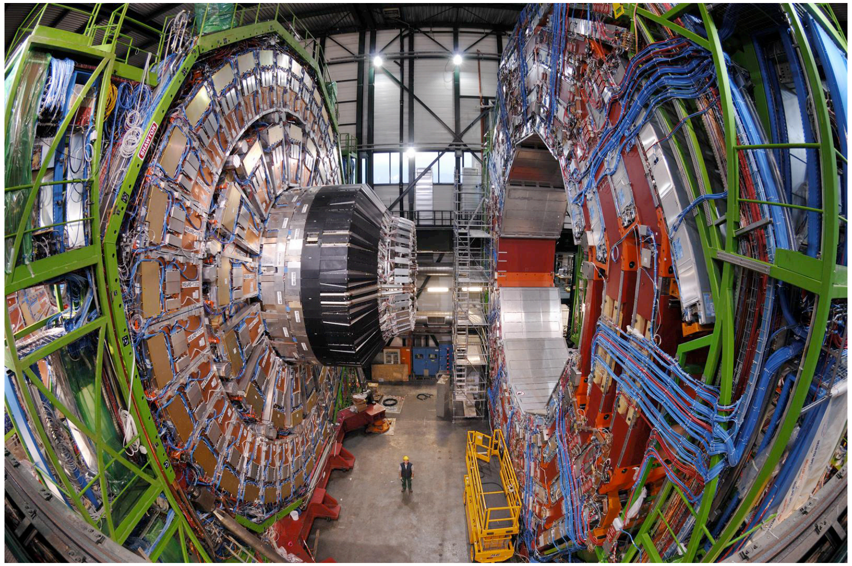
The CMS Experiment

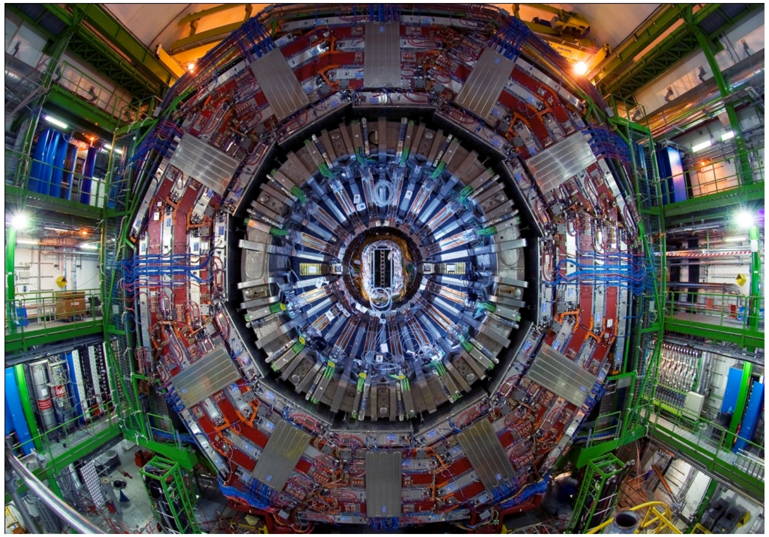
- Hadronic searches
- Leptonic searches
- Searches with photons

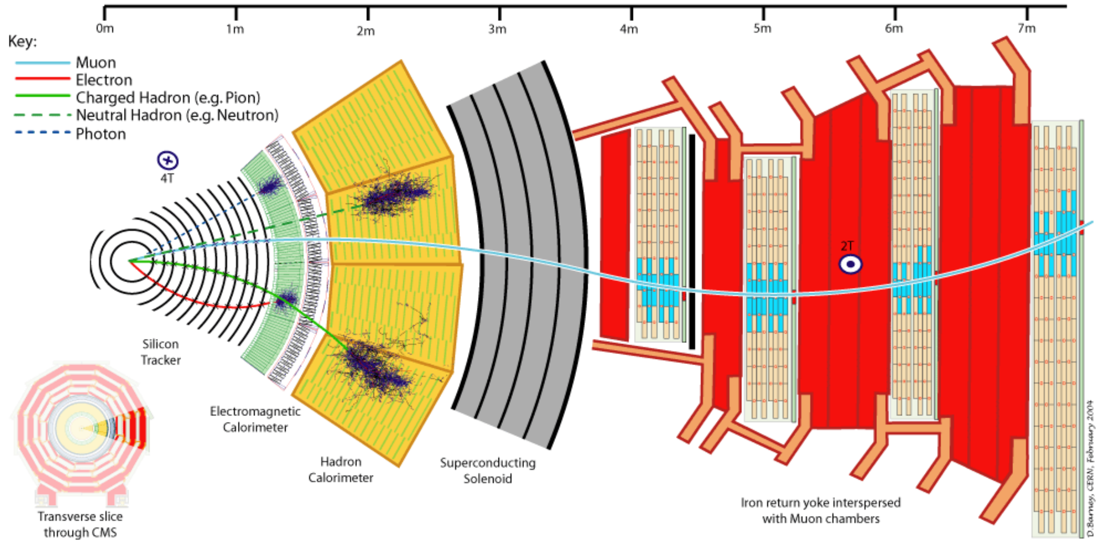


Compact Muon Solenoid (CMS)



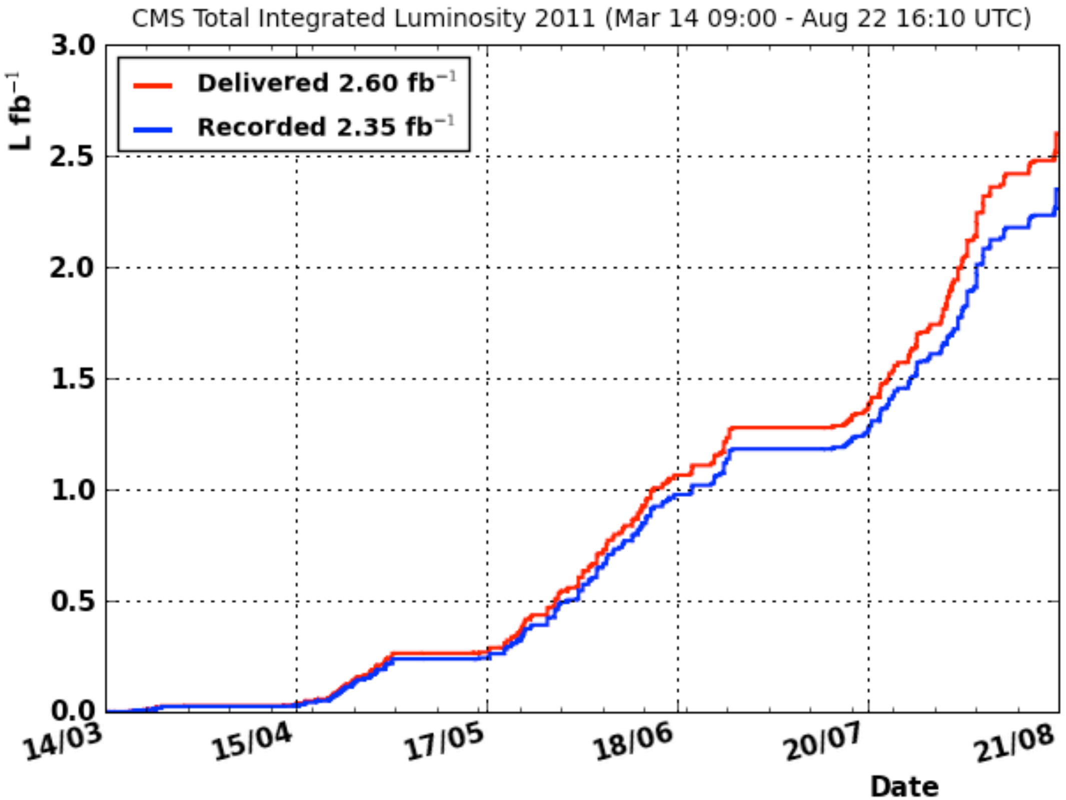






Luminosity accumulated so far

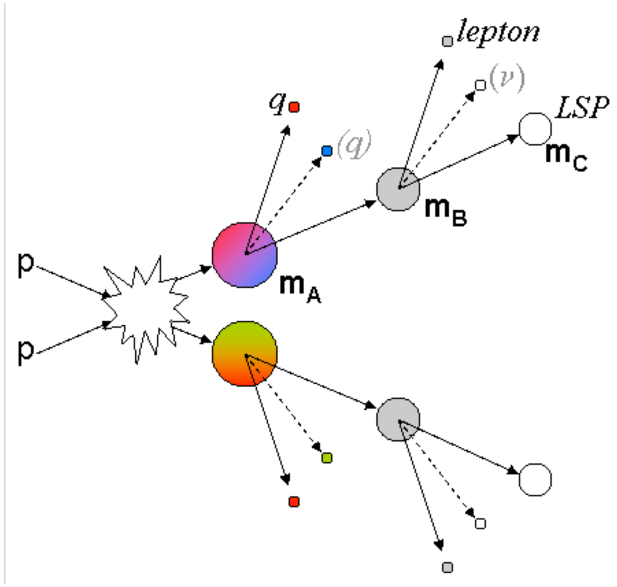
- More than 2.5 fb^{-1} accumulated so far
- Most analyses presented here are performed with ~ 1 fb^{-1}



CMS Search Strategy

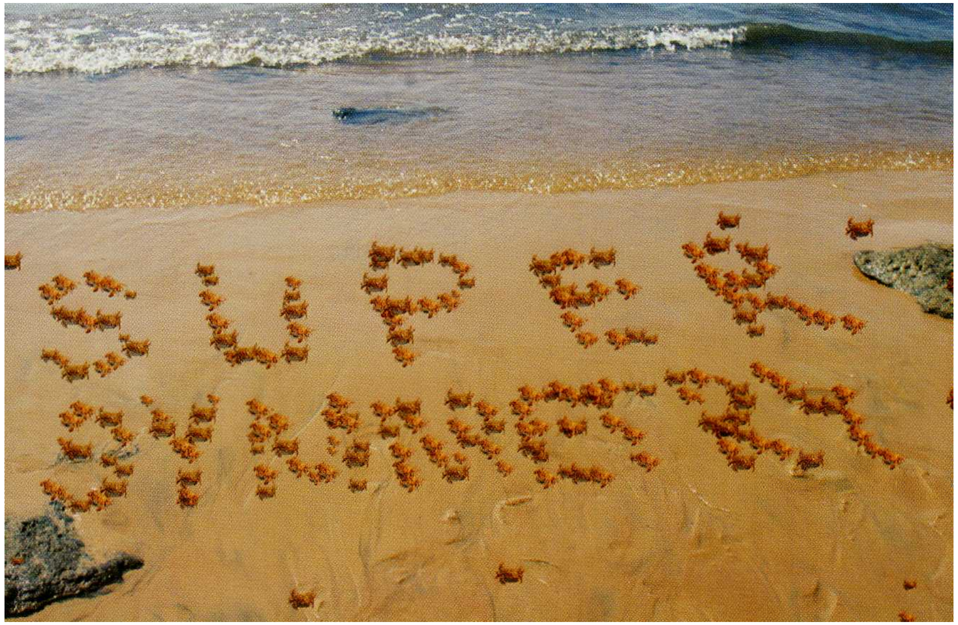
0 leptons	1 lepton	OSDL	SSDL	≥3 lep.	2 γ	1 γ+ 1 lep.
Jets + E_T^{miss} (+special variables)	Single lepton+ jets+E_T^{miss}	Opposite sign di-leptons+ jets+E_T^{miss}	Same-sign di-leptons + jets +E_T^{miss}	Multi-leptons	Di-photon +jets +E_T^{miss}	Photon +lepton +E_T^{miss}

- **Topology based searches, not optimized for any particular SUSY model**
- Most searches probe tails of $\mathbf{E_T^{miss}}$ distribution
- Try to cover as much phase space as possible (e.g. as low lepton p_T as possible)
- Estimate backgrounds from data (data-driven bkg estimate) to minimize reliance on MC (e.g. for detector (mis)reconstruction effects)



Where we are...

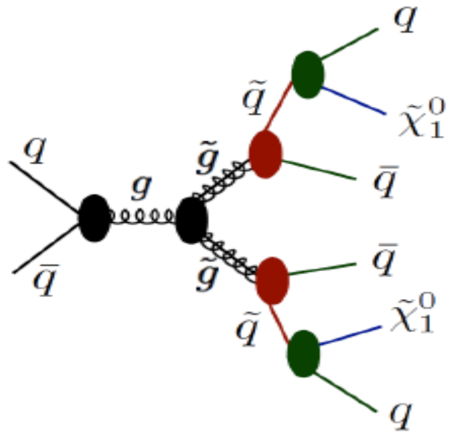
- The CMS Experiment
- **Hadronic searches**
  - Inclusive hadronic analysis
  - Inclusive analysis with M_{T2}
- Leptonic searches
- Searches with photons



Inclusive All-Hadronic Search: Introduction

Signature:
Many jets and large missing transverse energy

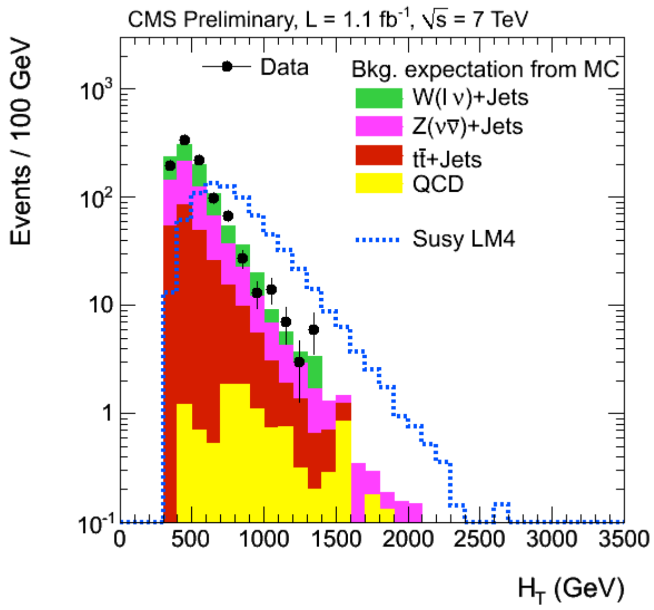
- Least model-dependent analysis
- Large backgrounds:
  - Z+jets with Z→ $\nu\nu$ (irreducible)
  - W+jets and ttbar with W → $l\nu$ and lost lepton or τ → hadrons + ν
  - QCD multijet events with large missing transverse momentum due to:
    - Leptonic decays of heavy flavor hadrons inside jets
    - Jet energy mismeasurement
    - Instrumental noise
    - Non-functioning detector components

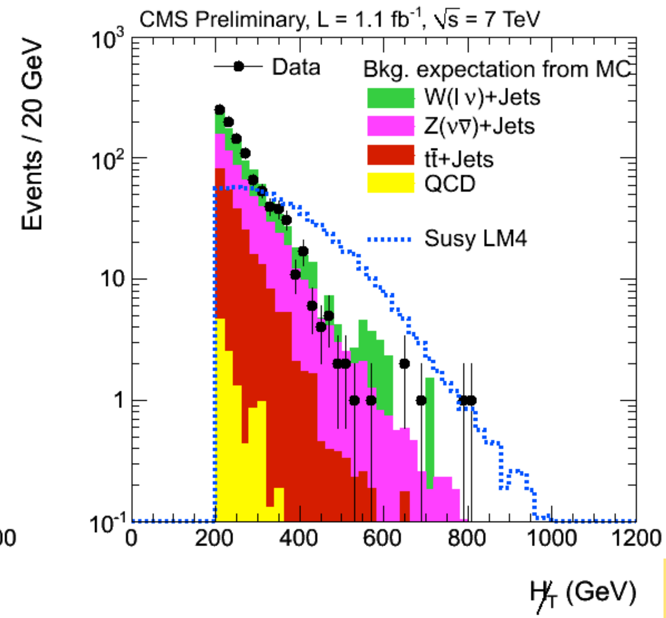


Phys. Lett. B698:196-218 (2011)
CMS PAS SUS-11-004

Inclusive All-Hadronic Search: Event Selection

- **Baseline selection**
  - At least 3 jets with $p_T^{jet} > 50$ GeV and $|\eta| < 2.5$
  - $H_T > 350$ GeV
  - $H_T^{miss} > 200$ GeV
  - $|\Delta\Phi(\vec{J}_{1,2}, \vec{H}_T^{miss})| > 0.5$ and $|\Delta\Phi(\vec{J}_3, \vec{H}_T^{miss})| > 0.3$ to veto events where H_T^{miss} is aligned in transverse plane with one of the 3 leading jets
  - Veto on isolated muons and electrons





$H_T = \Sigma |\vec{p}_T^{jet}|$

$\vec{H}_T^{miss} = -\Sigma\, \vec{p}_T^{jet}$

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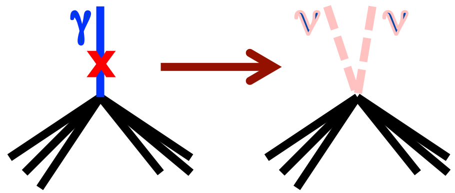
Inclusive All-Hadronic Search: Background Estimation for Z → νν

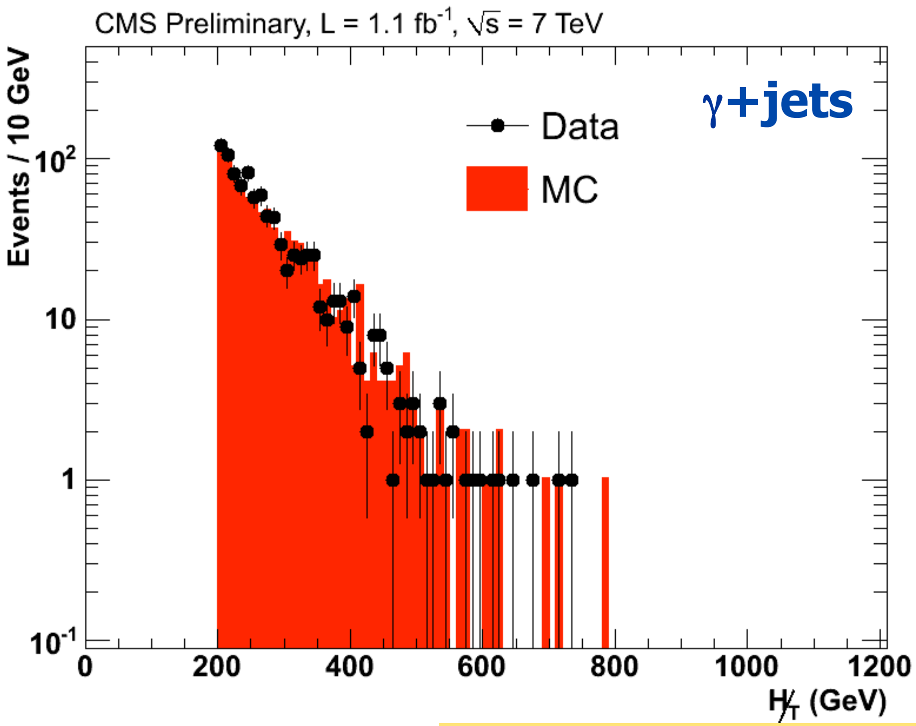
- **Background estimation with γ+jets :**
- Strategy:
  - Declare photon invisible to emulate neutrinos
  - Then re-calculate E_T^{miss} for this event
  - Correct for the photon reconstruction efficiency and neutrino branching ratio



SUSY signals could bias the prediction

→ Crosscheck with Z→μμ +jets:

→ Drawback: Low statistics in signal region, but comparable result in baseline selection



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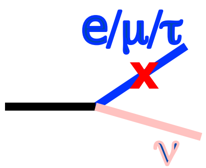
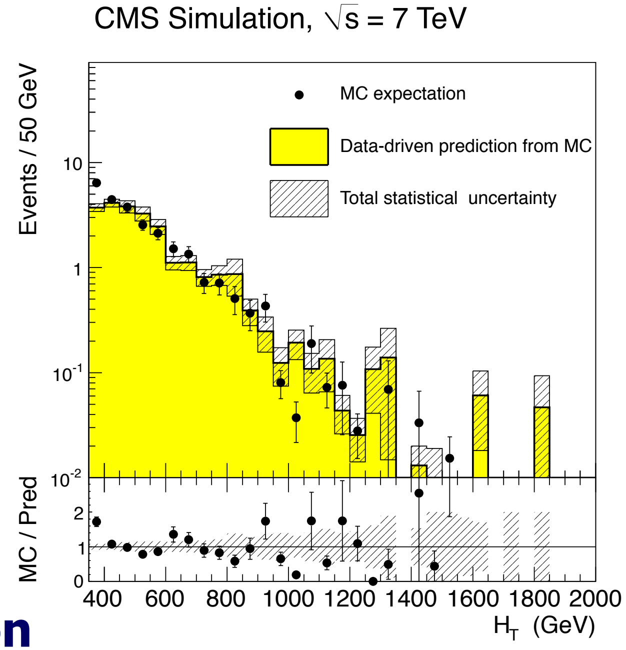
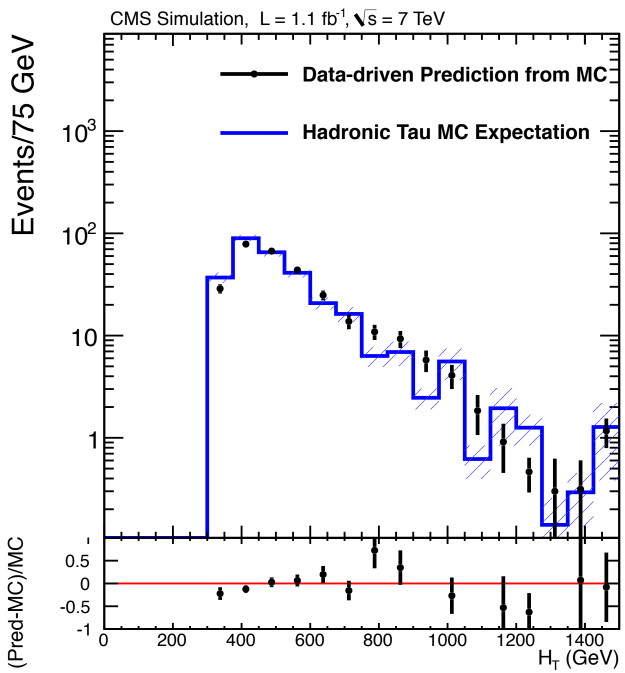
Inclusive All-Hadronic Search: W and Top Background Estimation



Lost Lepton Background Estimation

- Muon control sample with $M_T < 100$ GeV with $M_T=\sqrt{(2p_T^{\mu}\, E_T^{miss}\,(1-\cos\phi))}$ used to model:
  - Non-isolated (but identified) leptons
  - Non-identified leptons (ratio id/non-id taken from Monte Carlo)





τ Background Estimation

- Determined with a muon control sample
- Substitute μ with τ jet using response template to model the fraction of visible momentum
- Recalculate all quantities like H_T

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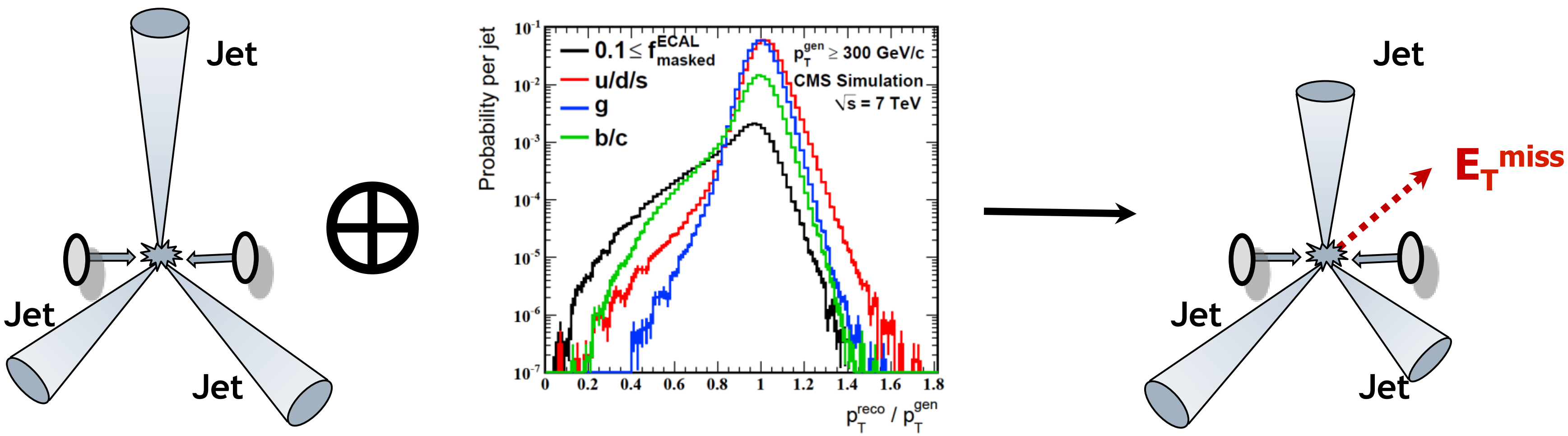
Inclusive All-Hadronic Search: QCD Background Estimation

- Most difficult background, derived here by 'Rebalance & Smear' method:
  - Rebalance all jets to overall p_T balance (=kind of 'generator level jet', robust against seed jet mismeasurements and non-QCD processes)
  - Smear p_T of each seed jet by a factor derived from jet resolution distribution (from simulation, and corrected for data/MC differences)
- Smearing of the jets results in artificially created E_T^{miss} used to estimate the real E_T^{miss} distribution



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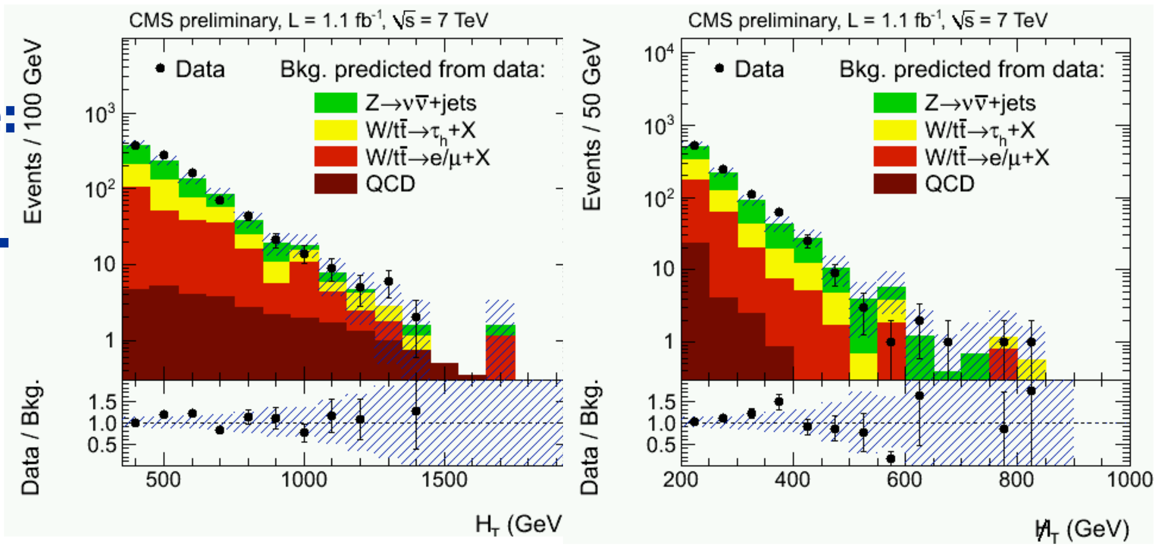
Inclusive All-Hadronic Search: Results

Method	**Baseline** H_T > 350 GeV and H_T^{miss} > 200 GeV	**Medium** H_T > 500 GeV and H_T^{miss} > 350 GeV	**High H_T** H_T > 800 GeV and H_T^{miss} > 200 GeV	**High H_T^{miss}** H_T > 800 GeV and H_T^{miss} > 500 GeV
$Z \to \nu\nu$ from γ+jets	376.3 ± 12.3 ± 79.2	42.6 ± 4.4 ± 8.9	24.9 ± 3.5 ± 5.2	2.4±1.1 ± 0.5
tt/W → e,μ+X	243.5 ± $19.8^{+30.0}_{-30.9}$	12.7 ± 3.3 ± 1.5	22.5 ± $6.7^{+3.0}_{-3.1}$	0.8±0.8 ± 0.1
tt/W → τ_{hadr}+X	263 ±8 ± 7.4	17 ± 2 ± 0.7	18 ± 2 ± 0.5	0.73 ± 0.73 ± 0.04
QCD	30.9 $\pm 35.2^{+16.6}_{-6.2}$	1.3 $\pm 1.3^{+0.6}_{-0.4}$	13.5 $\pm 4.1^{+7.3}_{-4.3}$	0.09 $\pm 0.31^{+0.05}_{-0.04}$
Total background	927.5 ±103.1	73.9 ±11.9	79.4 ±12.2	4.6 ±1.5
Observed in data	986	78	70	3

Here: Bkg pred. from data



No excess observed!

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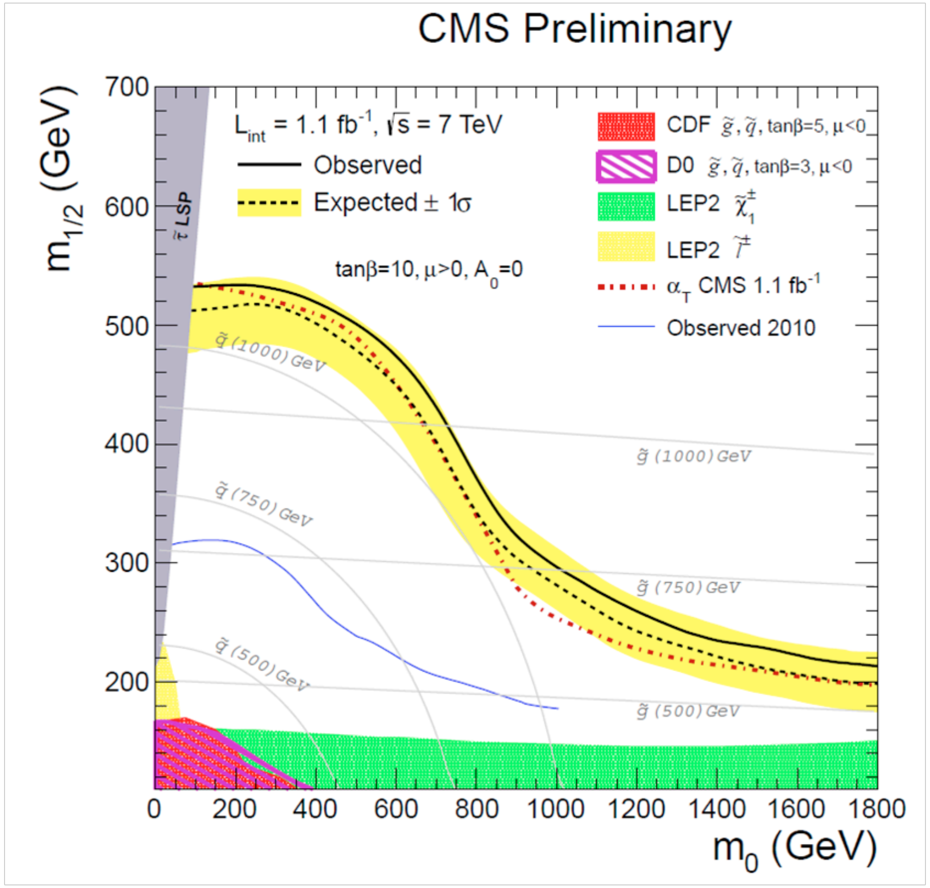
Inclusive All-Hadronic Search: Exclusion Plot

- Observed and expected 95% CL exclusion limit in the CMSSM m_0-$m_{1/2}$ plane using the signal cross sections calculated at NLO
- Contours are the combination of the different selections, such that the shown contours are the envelope with respect to best sensitivity



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Where we are...

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  - Inclusive hadronic analysis
  - Inclusive analysis with M_{T2}
- Leptonic searches
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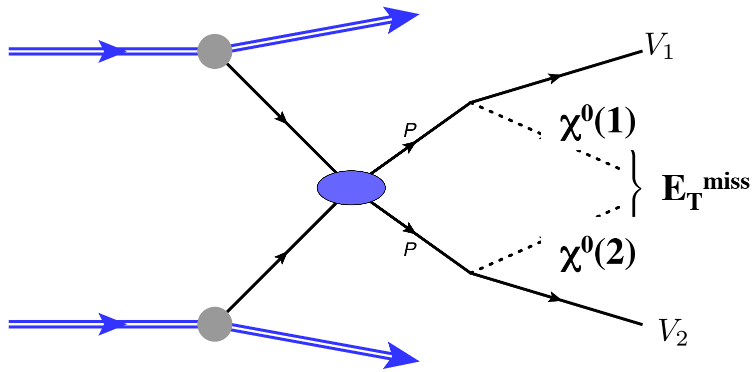
All-Hadronic Search with M_{T2} Method: Introduction

- M_{T2}: natural extension of M_T in case of SUSY with two colored sparticles decaying through cascade of jets (& leptons) to LSPs
- M_{T2} reflects masses of produced particles and is much lighter for SM than for most SUSY particles



- Definition of M_{T2}:

$$M_{T2} = \min_{p_T^{\chi(1)} + p_T^{\chi(2)} = p_T^{\text{miss}}} \left[\max\left(m_T^{(1)}, m_T^{(2)} \right) \right]$$

with m_T: transverse mass of sparticle decaying to visible system + LSP

$$m_T^{(i)} = \left(m^{\text{vis}(i)} \right)^2 + m_\chi^2 + 2\left(E_T^{\text{vis}(i)} E_T^{\chi(i)} - \vec{p}_T^{\,\text{vis}(i)} \cdot \vec{p}_T^{\,\chi(i)} \right)$$

- m_χ remains free parameter, minimized fulfilling E_T^{miss} constraint
- For correct m_χ: distributions of $m_T^{(i)}$ have an endpoint at value of primary sparticle mass

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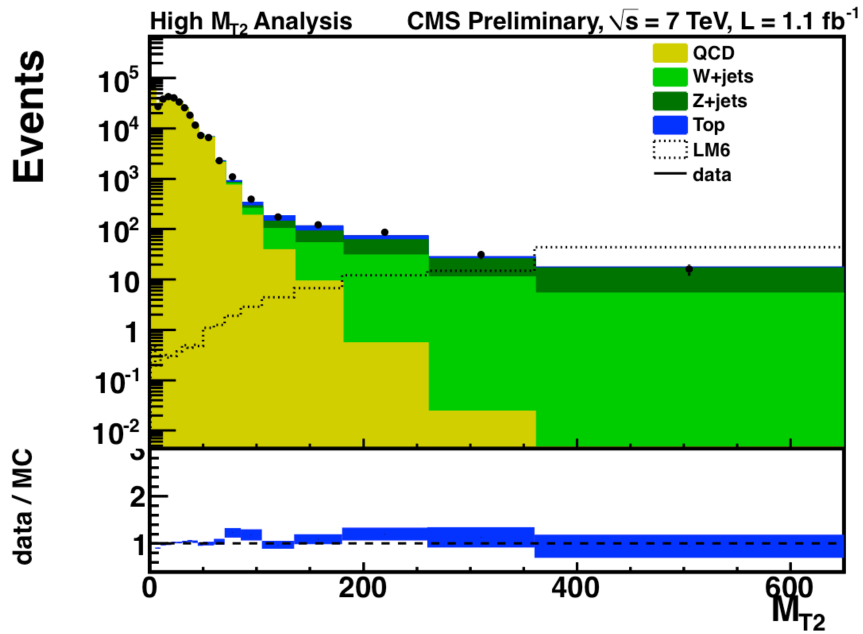
All-Hadronic Search with M_{T2} Method: Event Selection

- **Baseline selection**
  - At least 3 jets with $p_T^{jet1,jet2} > 100$ GeV and $|\eta| < 2.4$
  - $E_T^{miss} > 30$
  - $|\vec{H}_T^{miss} - \vec{E}_T^{miss}| < 70$ GeV
  - $|\Delta \Phi (\vec{p}_T^{jet}, \vec{E}_T^{miss})| > 0.3$
  - Veto on isolated muons and electrons

- **Search regions**
  - *High M_{T2} analysis:*
    - $H_T > 600$ GeV
    - $M_{T2} > 400$ GeV
  - *Low M_{T2} analysis:*
    - ≥ 4 jets
    - ≥ 1 b-tagged jet
    - $H_T > 650$ GeV
    - $M_{T2} > 150$ GeV



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All-Hadronic Search with M_{T2} Method: Background Estimation

High M_{T2} analysis:

- QCD estimation:
  - Factorization (ABCD) method with $\Delta\phi_{min}$ (azimuth angle between E_T^{miss} and closest jet) and M_{T2}
  - Correlation between $\Delta\phi_{min}$ and M_{T2} is parameterized in control region (50 GeV < M_{T2} < 80 GeV) and extrapolated to higher M_{T2}
- Background from W+jets, ttbar
  - Leptonic W decay with *lost lepton* or τ *decays*
    - → Similar estimation as in previously described analysis
- Background from Z → $\nu\nu$
  - → Obtained from W → $l\nu$ + jets, where the lepton is added to E_T^{miss}

Low M_{T2} analysis:

- Estimated similarly as for high M_{T2} analysis on pre-b-tagged sample to have enough statistics
  (Ratio of b-tagged/pre-b-tagged sample constant vs. M_{T2})

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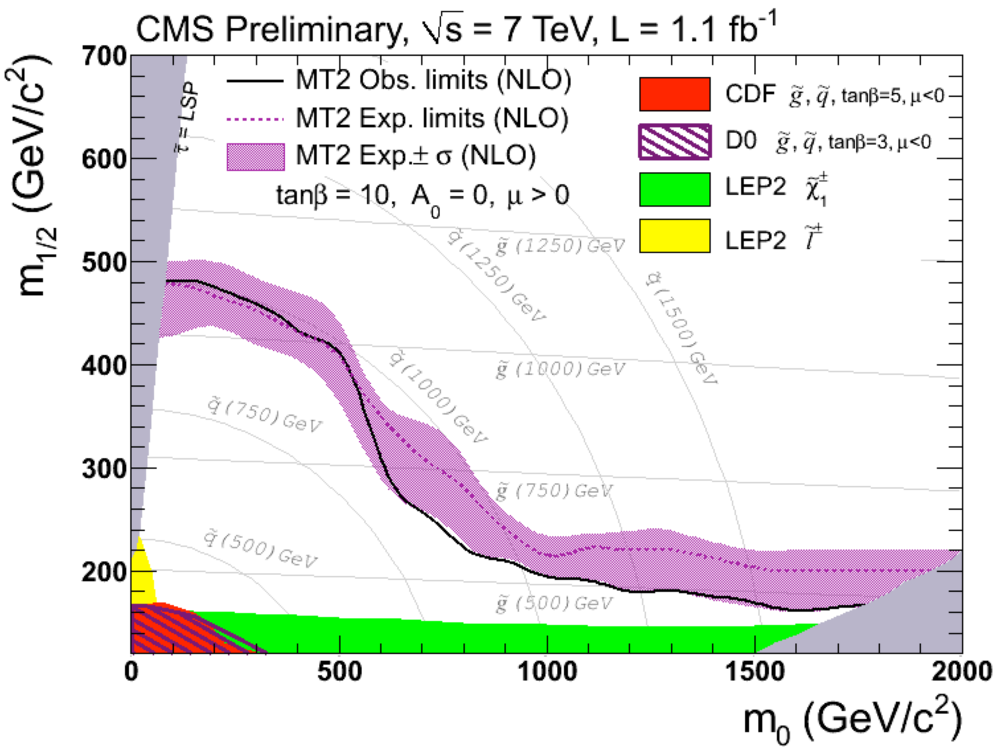
All-Hadronic Search with M_{T2} Method: Results

Analysis	Predicted BG	Data	σ x BR (pb)	
			observed limit	expected limit
High M_{T2}	12.6 ± 1.3 ± 3.5	12	0.010	0.011
Low M_{T2}	10.6 ± 1.9 ± 4.8	19	0.020	0.014



- Background in low M_{T2} mass analysis probably underestimated due to statistical fluctuation in the control region

No excess observed!

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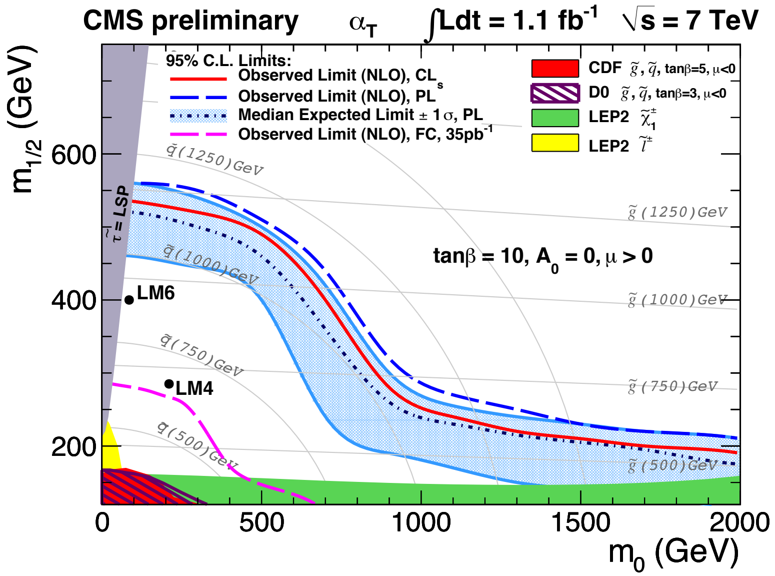
Other Hadronic Analyses

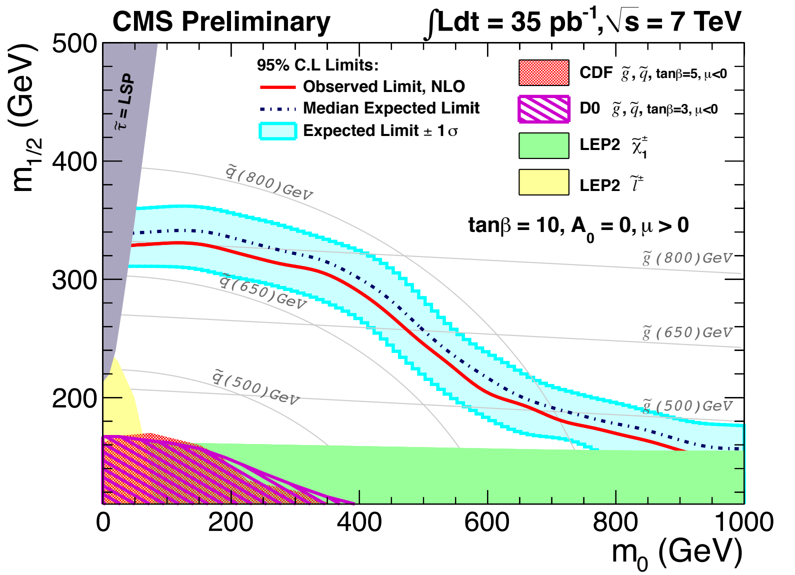
- Kinematic variable α_T :
  - Robust against QCD background
  - Updated 2011 with shape analysis

$$\alpha_T = \frac{\sqrt{E_T^{j2} / E_T^{j1}}}{\sqrt{2\left(1\text{-}\cos\Delta\varphi\right)}}$$



Phys. Lett. B698:196-218 (2011)
CMS PAS SUS-10-003
CMS PAS SUS-11-001
CMS PAS SUS-11-003

- Razor variables:
  - Designed to characterize pair-production of heavy particles
  - Combine all particles into two hemispheres, then boost back to rest-frame (update soon!)

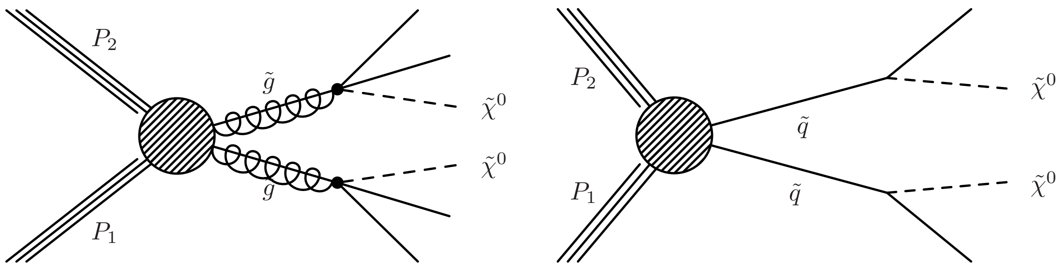


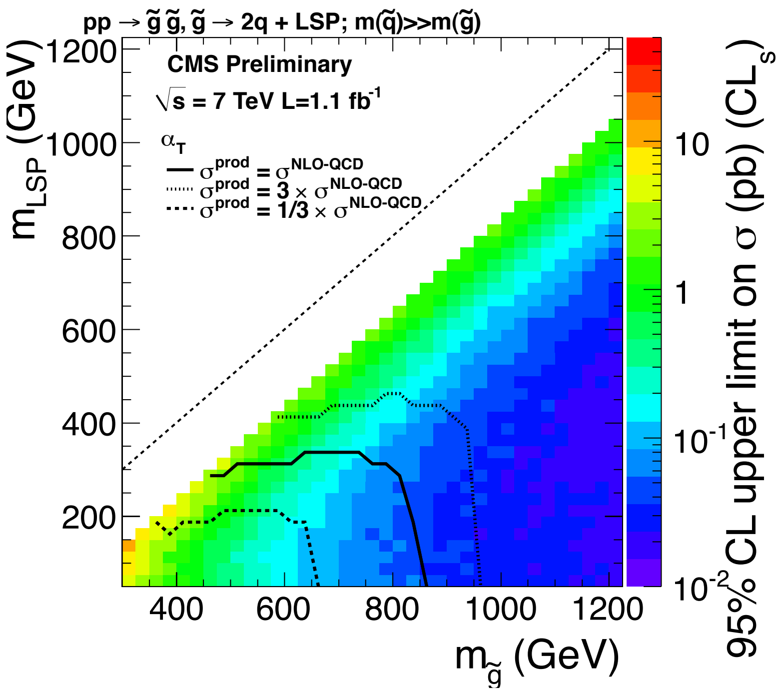
arxiv:1107.1279
CMS PAS SUS-10-009

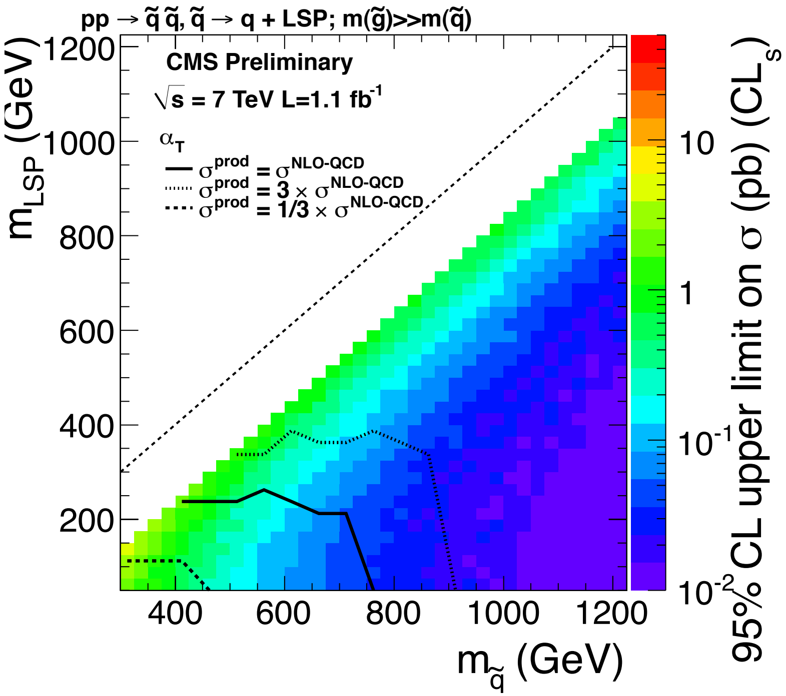
Hadronic Analysis: Interpretation

- Simplified models (on-shell effective theory): intermediate step between a complete theory and experimental signature

From data in CMS PAS SUS-11-003







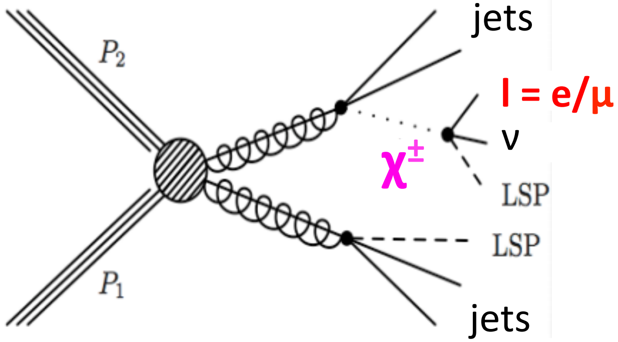
Where we are...

- The CMS Experiment
- Hadronic searches
- **Leptonic searches**
  - → Searches including one lepton ←
  - → Searches with opposite-sign leptons / Z
- Searches with photons

Searches including one Lepton: Introduction

Signature:
Exactly one lepton, several jets and large missing transverse energy

- QCD background reduced by 1 lepton requirement



$\chi^{\pm}$

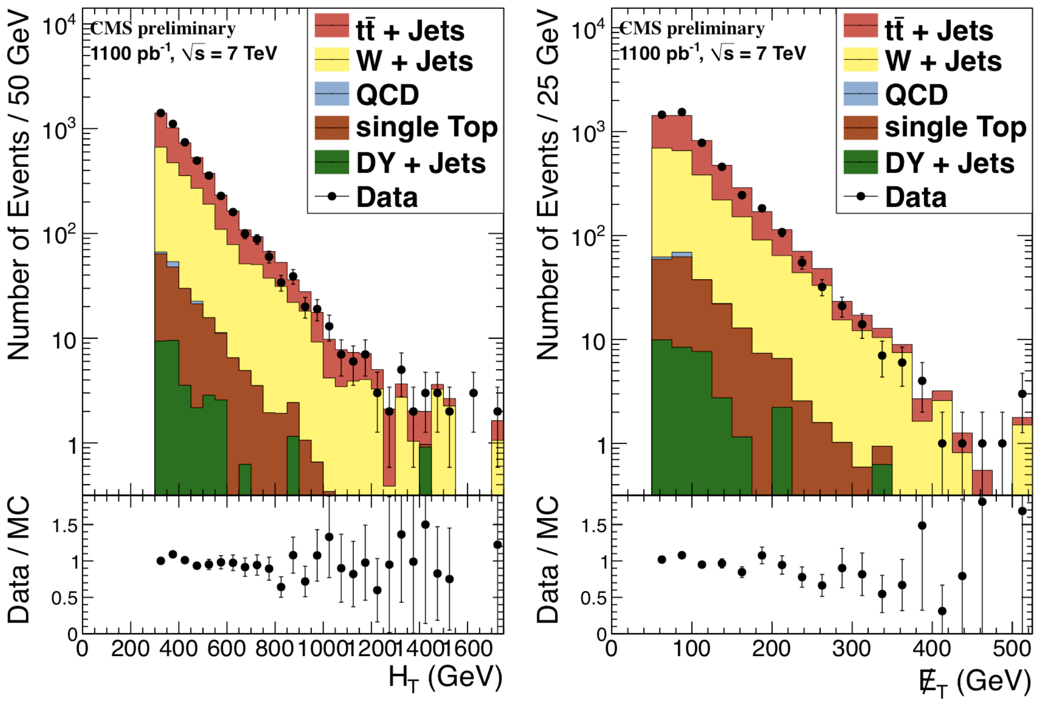
- Two complementary methods to determine the remaining background:
  - *Lepton spectrum method*
    - Prediction of E_T^{miss} spectrum with the observed lepton spectrum
  - *Lepton projection method*
    - Sensitive to the helicity angle of the lepton in the W rest frame

$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

CMS PAS SUS-11-015

Searches including one Lepton: Event selection

- **Baseline selection**
  - At least 3 (4) jets with p_T > 40 GeV and $|\eta|$ < 2.4
  - Exactly 1 isolated muon or electron with
    - p_T^{μ} > 20 GeV and $|\eta|$ < 2.1
    - p_T^{e} > 20 GeV and $|\eta|$ < 2.4, excluding 1.44 < $|\eta|$ < 1.57
    - Relative isolation: $I = \Sigma(E_{T(Cal.)}+P_{T(Tracker)})/p_T^{lep} < 0.1\ (\mu)$, $I < 0.3$ (e)



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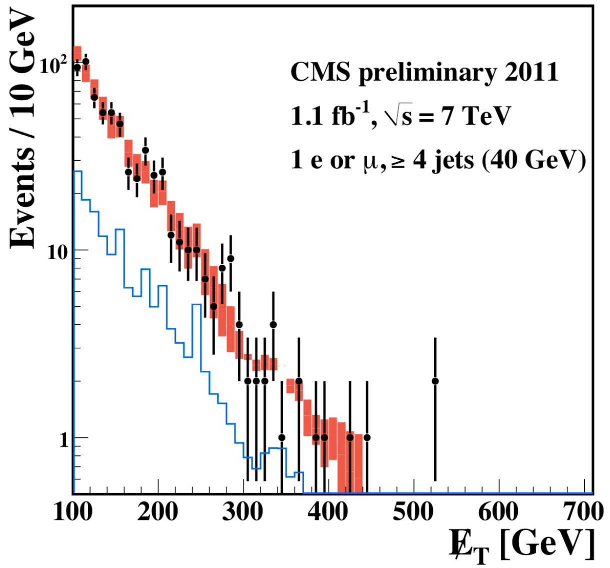
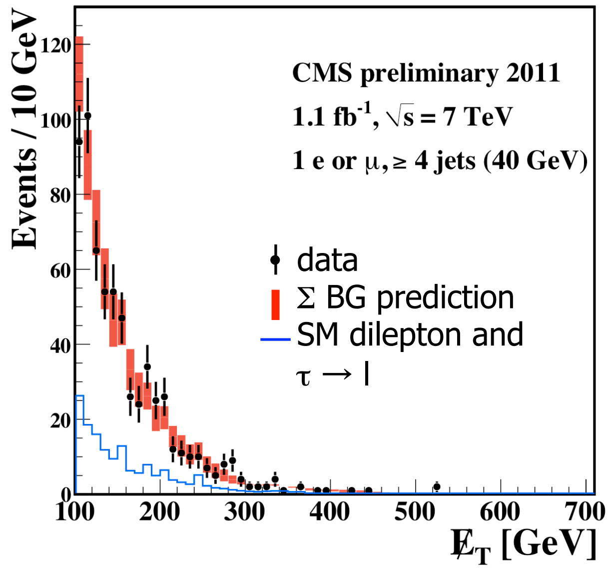
Searches including one Lepton: BG with Lepton Spectrum Method

- Idea: in W decays the charged lepton and neutrino p_T spectrum are related
  - Take muon p_T spectrum
  - Correct for acceptance, efficiency and polarization effects
  - E_T^{miss} resolution worse than e/mu → smear muon p_T





- Remaining background:
  - Di-leptons
  - τ

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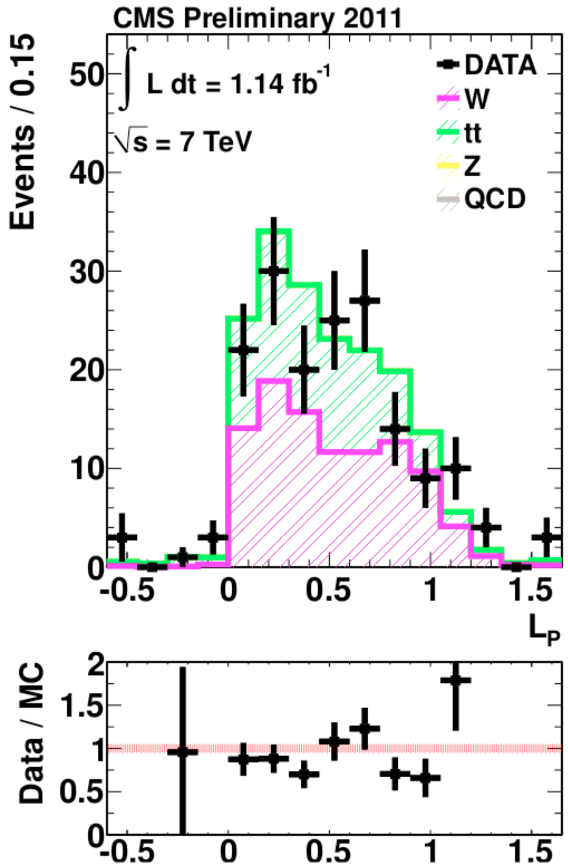
Searches including one Lepton: BG with Lepton Projection Method

- SM background in signal region predicted by

$$\underbrace{N_{\text{pred}}(L_P < 0.15)}_{\text{signal region}} = R\, \underbrace{N_{\text{data}}(L_P > 0.30)}_{\text{norm. region}}$$

with $R = \dfrac{N_{\text{MC}}(L_P < 0.15)}{N_{\text{MC}}(L_P > 0.30)}$



In addition: data-driven estimation of QCD background due to fake electrons

- Analysis is performed in several bins of the (leptonic) mass scale: $S_T^{lep} = |p_T^{lep}| + |E_T^{miss}|$

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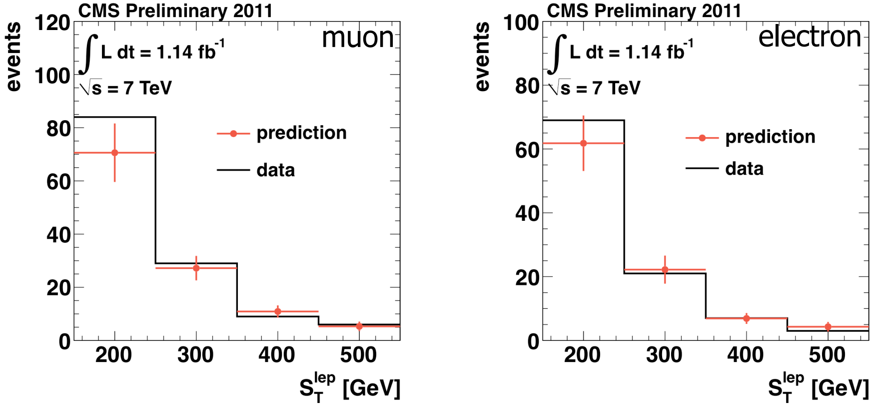
Searches including one Lepton: Results

- **Lepton spectrum method:**

Sample	**Loose selection** $H_T > 500$ GeV, $E_T^{miss} > 250$ GeV	**Tight selection** $H_T > 500$ GeV, $E_T^{miss} > 350$ GeV
Total predicted SM	49.8 ± 8.8 ± 10.8	12.1 ± 4.3 ± 3.6
Data	52	8

- **Lepton projection method:**

S_T^{lep} range/GeV	**SM estimate μ**	**Data μ**	**SM estimate e**	**Data e**
150 – 250 (control sample)	70.6 ± 11	84	61.8±8.7	69
250 – 350	27.2 ± 4.6	29	22.2±4.4	21
350 – 450	10.9 ± 2.3	9	6.9±1.7	7
>450	5.3 ± 1.8	6	4.3±1.5	3



No excess observed!

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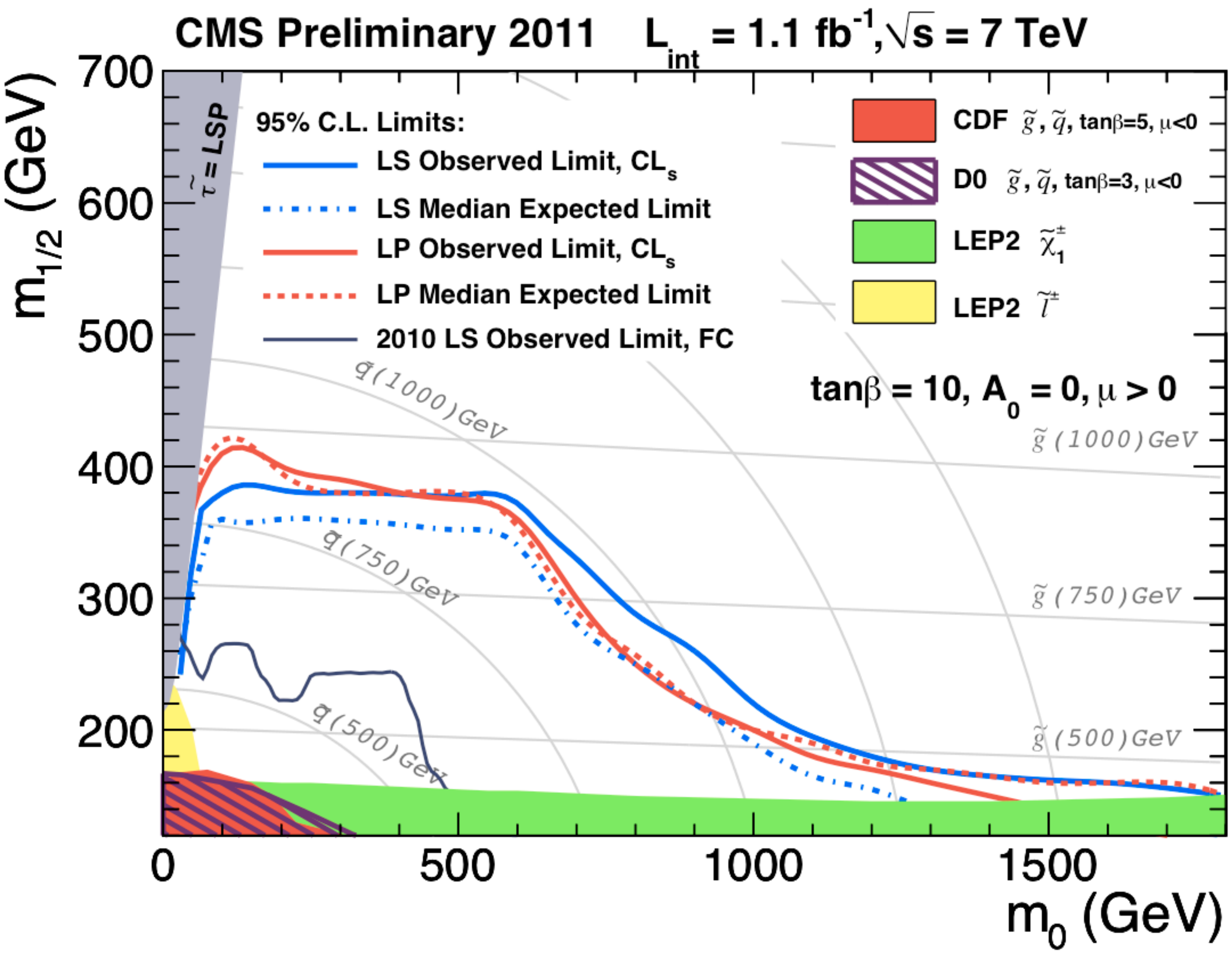
Searches including one Lepton: Exclusion Limits



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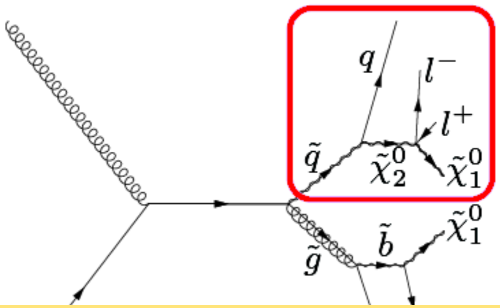
Where we are…

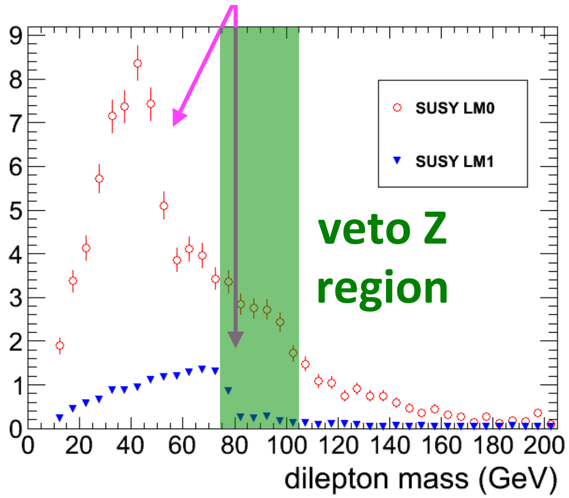
- The CMS Experiment
- Hadronic searches
- **Leptonic searches**
  → Searches including one lepton
  ⇒ Searches with opposite-sign leptons ⇐
- Searches with photons

Opposite Sign Di-Leptons: Introduction

Opposite-sign di-leptons can have two sources:

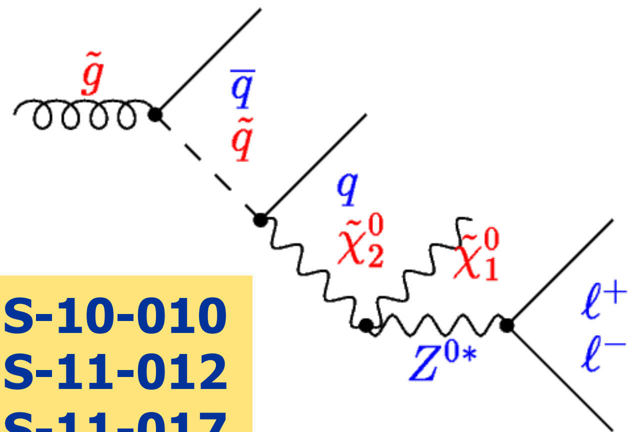
- Neutralino decays

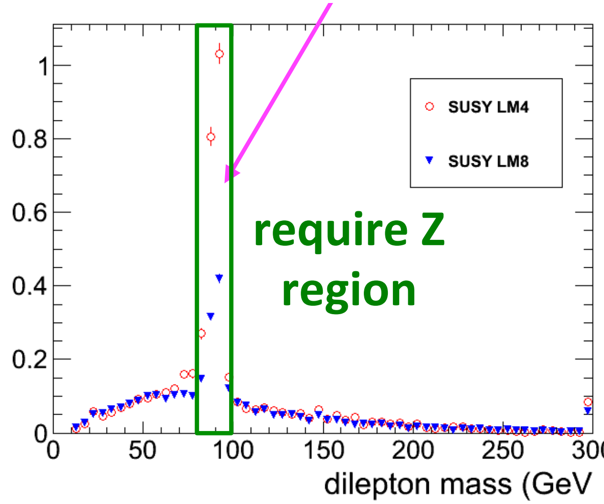




Phys. Rev. Lett. 106, 211802 (2011)
CMS PAS SUS-11-011

- Z production

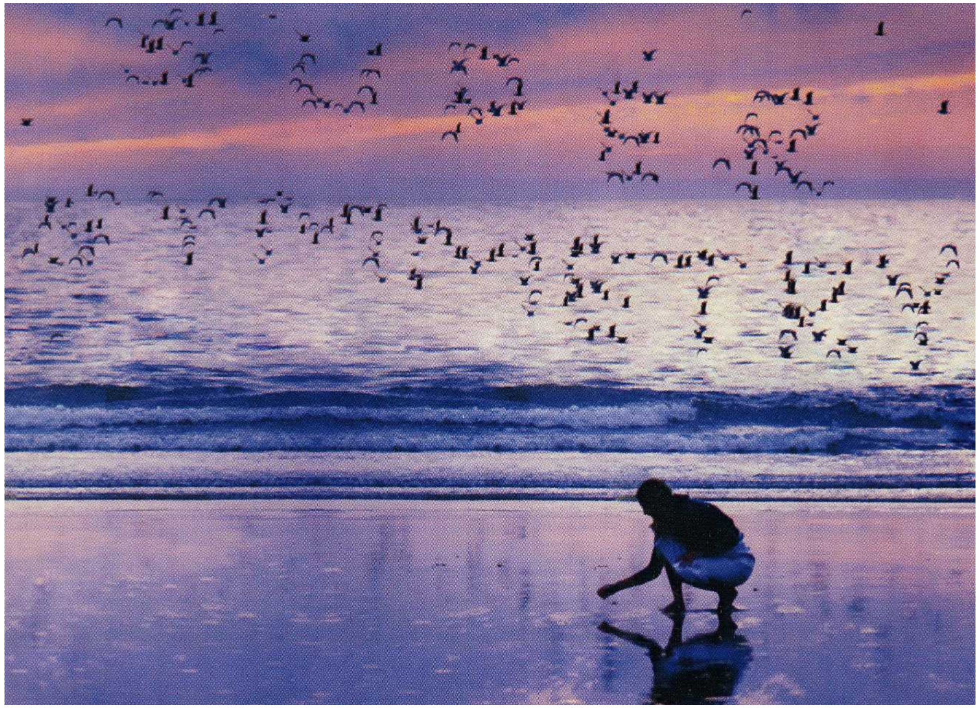




CMS PAS SUS-10-010
CMS PAS SUS-11-012
CMS PAS SUS-11-017

Where we are…

- The CMS Experiment
- Hadronic searches
- **Leptonic searches**
  → Searches including one lepton
  → Searches with opposite-sign leptons outside the Z region
  → Searches with opposite-sign leptons in the Z region
- Searches with photons



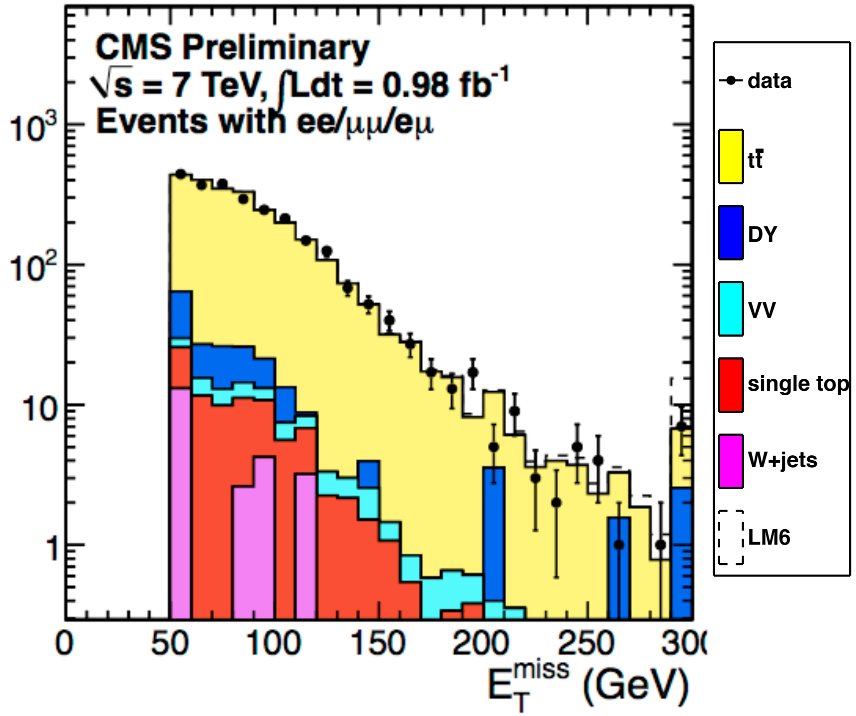
Opposite Sign Di-Leptons: Event Selection outside Z-region

- **Baseline selection**
  - $p_T^{lep1} > 20$ GeV, $P_T^{lep2} > 10$ GeV, $|\eta| < 2.4$ (μ) and $|\eta| < 2.5$ (e)
  - Relative isolation : $I = \Sigma(E_{T(Cal.)}+P_{T(Tracker)})/p_T^{lep} < 0.15$ for leptons
  - At least 2 jets with $p_T > 30$ GeV, $|\eta| < 3$ and $\Delta R=0.4$ to leptons
  - $H_T > 100$ GeV, $E_T^{miss} > 50$ GeV

- ***Counting experiments:***
  - Exclude Z and low mass resonances

- ***Kinematic edge measurement:***

  Use opposite flavor to determine bkg (signal expected in same flavor sample)
  - $E_T^{miss} > 100$ GeV (to remove DY)



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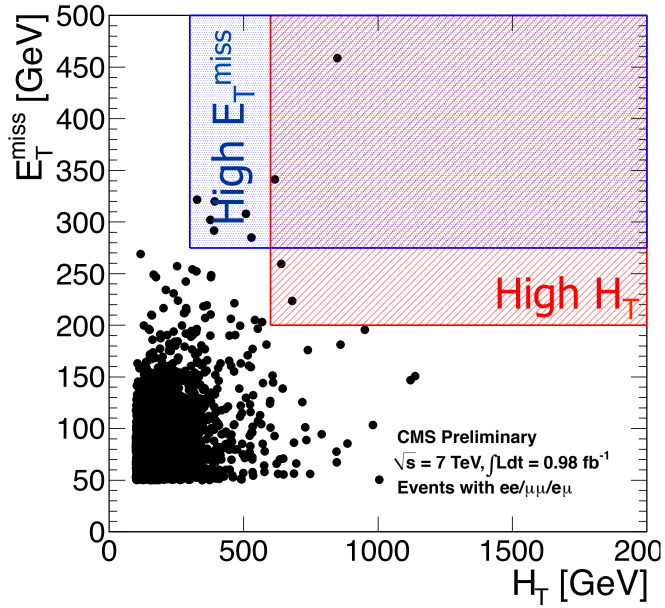
Opposite Sign Di-Leptons: Counting Experiments

Three independent methods to estimate the background (data-driven)

- Factorization method (ABCD′) with H_T and $y=E_T^{miss}/\sqrt{H_T}$:
  - Derive background in signal region D from events in control regions ABC
  - Small correlation taken into account including a correction factor

- Di-lepton spectrum method:
  - Similar to lepton spectrum method in 1-lepton case

- Comparison of same-flavor to different-flavor
  - Expect excess of same-flavor vs different-flavor events in BSM, while rates should be similar for ttbar (different reconstruction efficiencies for μ and e taken into account)



No excess observed!

CMS PAS SUS-11-011

Opposite Sign Di-Leptons: Kinematic Edge Measurement

- Dominant background (ttbar, WW, DY → ττ): flavor is uncorrelated

→ Use different flavor to predict background in same-flavor signal sample

- Signal fit (edge model for two subsequent 2-body decays):

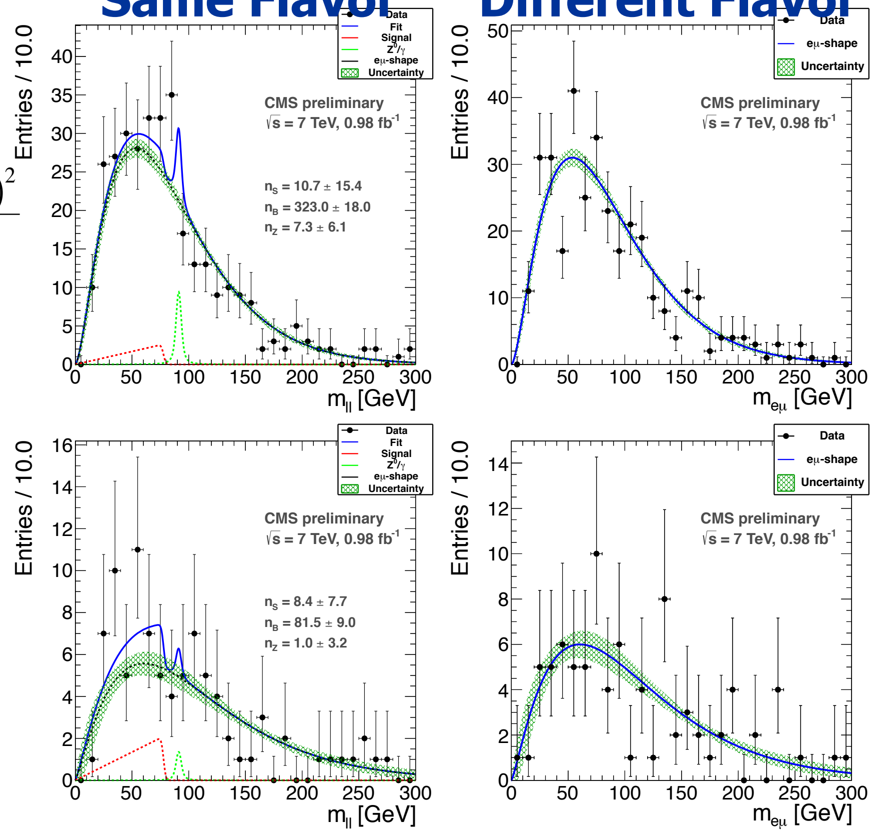
$$T(m_{ll}) = \frac{1}{\sqrt{2\pi}\sigma_{ll}} \int_0^{M_{cut}} dy\, y e^{-\frac{(m_{ll}-y)^2}{2\sigma^2}}$$

- Z modeled by Breit-Wigner convoluted with Gaussian (fixed Z mass and width)
- Background fit:

$$B(m_{ll}) = m_{ll}^{a} e^{-b m_{ll}}$$

→ Simultaneous, extended, unbinned ML fit in SF and DF events

Same Flavor **Different Flavor**



Control Region $100 < H_T < 300$ GeV

Signal Region $H_T > 300$ GeV

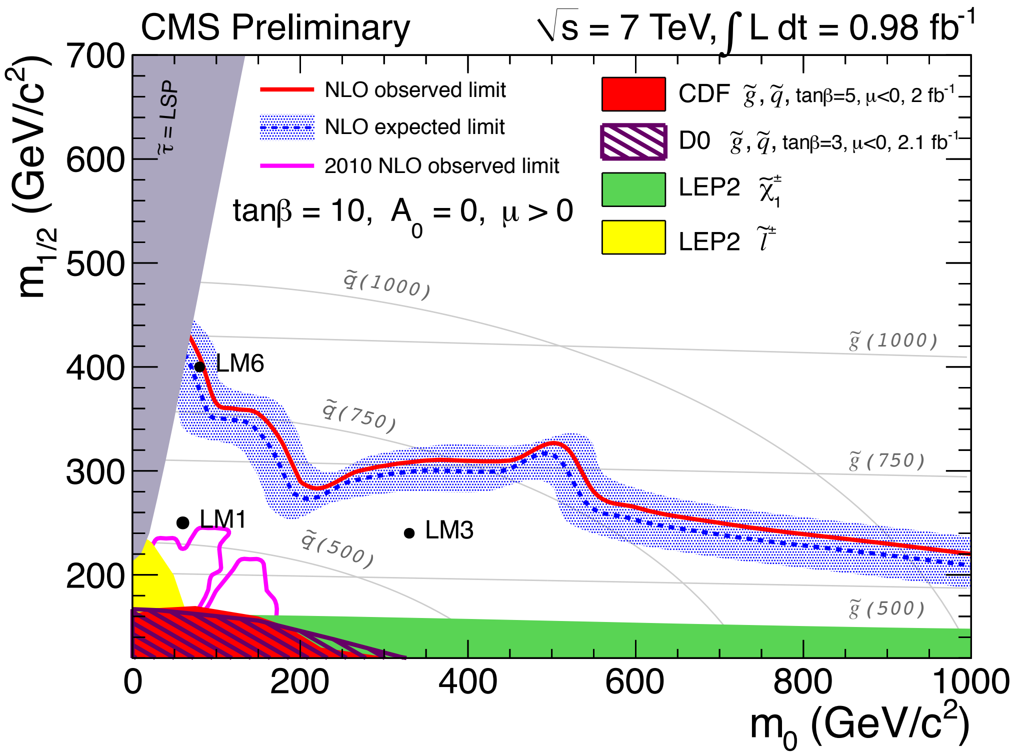
No excess observed!

CMS PAS SUS-11-011

Opposite Sign Di-Leptons: Results

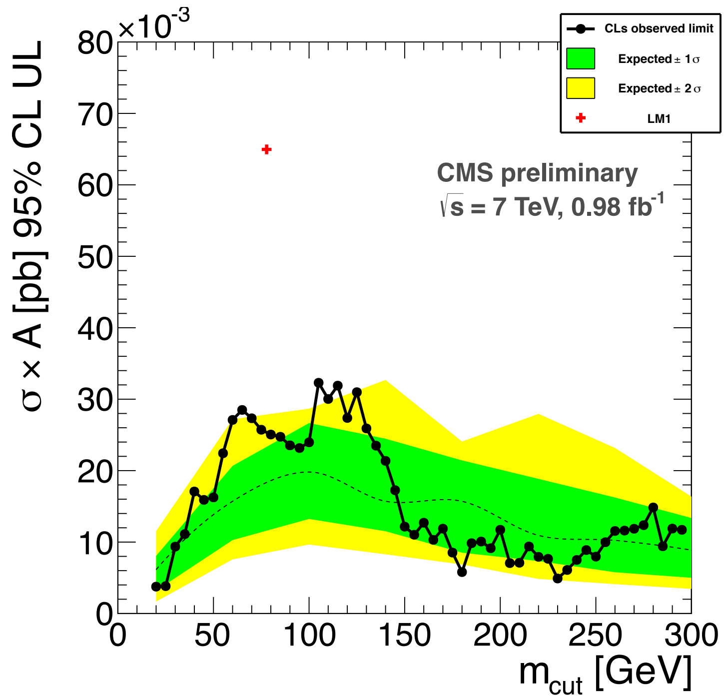
Counting experiment

- 95 % CL exclusion contour at NLO in the CMSSM plane with ±1 σ variation



Kinematic edge measurement

- 95 % CL upper limit on cross section times acceptance as function of the endpoint in the mass spectrum assuming triangular shaped signal



(More tables with results in backup)

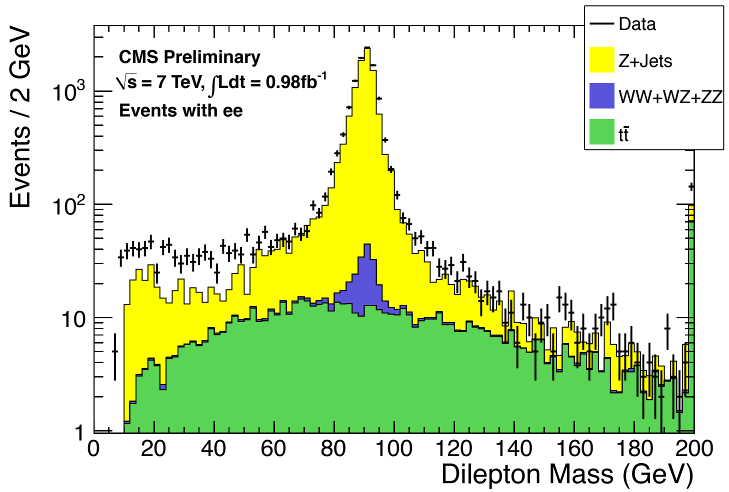
CMS PAS SUS-11-011

Where we are...

- The CMS Experiment
- Hadronic searches
- **Leptonic searches**
  - → Searches including one lepton
  - → Searches with opposite-sign leptons outside the Z region
  - ⇒ Searches with opposite-sign leptons in the Z region ⇐
- Searches with photons

Opposite Sign Di-Leptons: Event Selection on Z-region

- New physics expected to connect to EW sector, e.g. $\chi_2^0 \rightarrow Z\ \chi_1^0$
- **Baseline selection**
  - $p_T^{lep1,lep2} > 20$ GeV, $|\eta| < 2.4$ (μ) and $|\eta| < 2.5$ (e)
  - Relative isolation : $I = \Sigma(E_{T(Cal.)}+P_{T(Tracker)})/p_T^{lep} < 0.15$ for leptons
  - At least 2 jets with $P_T > 30$ GeV, $|\eta| < 3$ and $\Delta R=0.4$ away from leptons
  - 81 GeV > $m_{lep,lep}$ < 101 GeV



- **Two search strategies**
  - ***E_T^{miss} measurement:***
    - $E_T^{miss} > 100$ (200) GeV
  - ***Jet-Z balance method:***
    - At least 3 jets with $P_T > 30$ GeV, $|\eta| < 3$ and $\Delta R=0.4$ away from leptons
    - *Loose selection:* JZB = $|\Sigma\ \vec{p}_T^{jets}| - |\vec{p}_T^{Z}| > 50$ GeV
    - *Tight selection:* JZB > 100 GeV

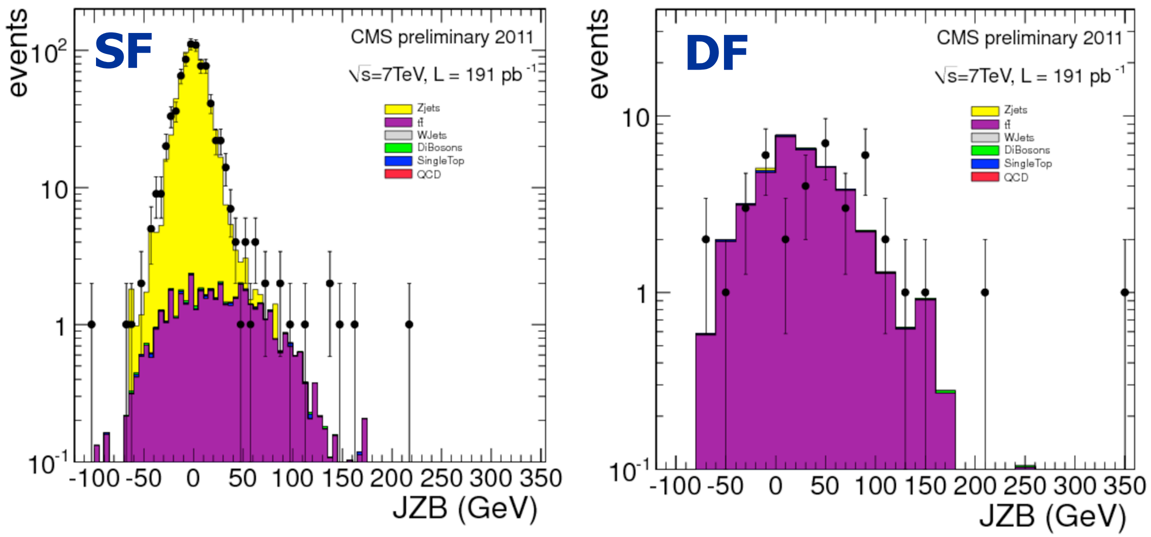
CMS PAS SUS-11-012
CMS PAS SUS-11-017

Opposite Sign Di-Leptons: Background Determination (Z-region)

- **E_T^{miss} measurement:**
  - Artificial E_T^{miss}: use templates from γ+jet or QCD multi-jet events
  - ttbar estimation: subtract different-flavor contribution (without Z mass constraint) from same-flavor sample

- **Jet-Z balance method:**
  - Total SM background in JZB > 0:

$$JZB_{bkg}^{pred} = \left| JZB_{SF}^{neg} - JZB_{DF}^{neg} \right| + JZB_{DF}^{pos}$$

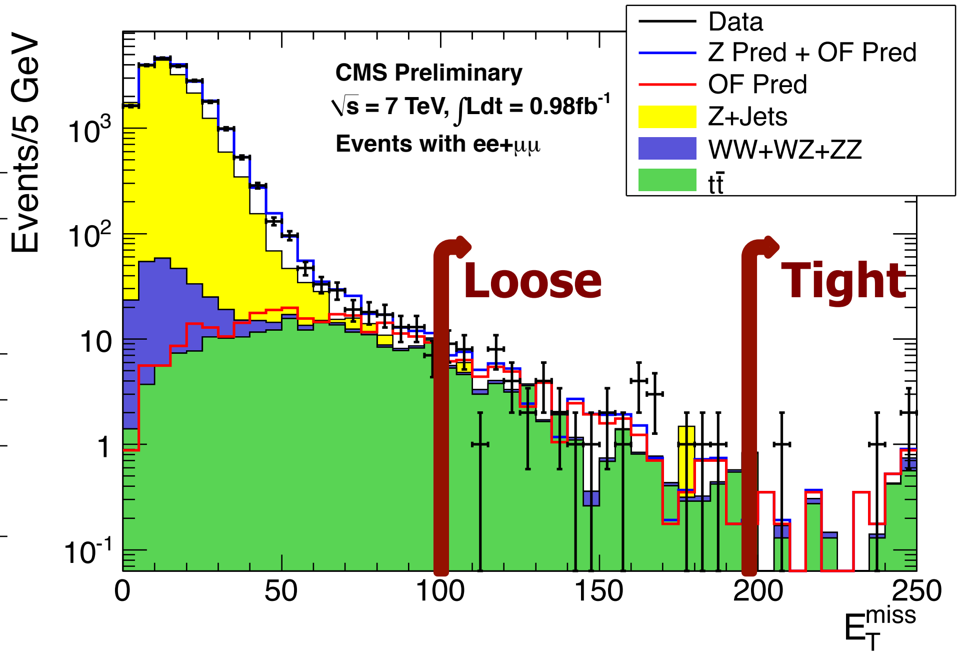


CMS PAS SUS-11-012
CMS PAS SUS-11-017

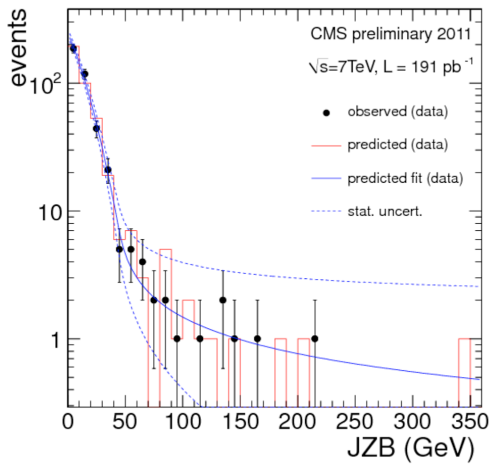
Opposite Sign Di-Leptons: Results (Z-region)

- **E_T^{miss} measurement:**

	Loose $E_T^{miss} > 100$ GeV	Tight $E_T^{miss} > 200$ GeV
Z Pred	$5.1 \pm 1.0 \pm 0.8$	$0.09 \pm 0.04 \pm 0.01$
$t\bar{t}$ Pred	$50.6 \pm 2.8 \pm 4.6$	$3.2 \pm 0.7 \pm 0.3$
Prediction	$55.7 \pm 3.0 \pm 4.6$	$3.3 \pm 0.7 \pm 0.3$
Data	**57 (25,32)**	**4 (1,3)**
UL	20	5.9
LM4	20.1 ± 1.7	12.3 ± 1.7
LM8	8.7 ± 0.8	5.0 ± 0.7



- **Jet-Z balance method:**



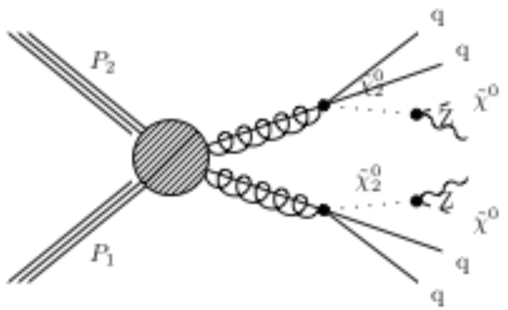
Sample	Loose selection JZB > 50 GeV	Tight selection JZB > 100 GeV
MC expectation	16.0 ± 1.2	3.6 ± 0.4
Total predicted SM	$24 \pm 6_{stat} \pm 1.4_{peak}\,^{+1.2}_{-2.4\,sys}$	$8 \pm 4_{stat} \pm 0.1_{peak}\,^{+0.4}_{-0.8\,sys}$
Data	20	6

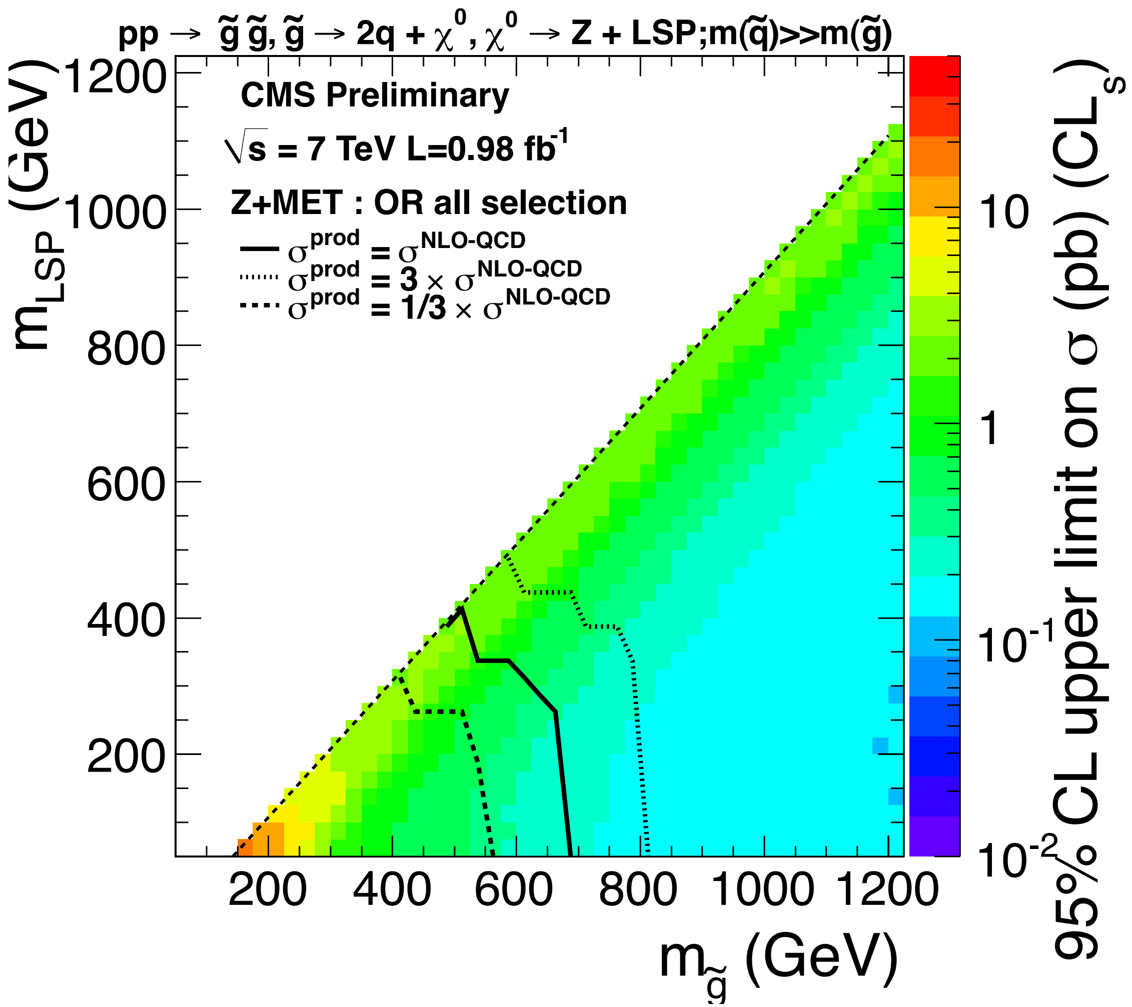
No excess observed!

CMS PAS SUS-11-012
CMS PAS SUS-11-017

Opposite Sign Di-Leptons: Interpretation

- Simplified model

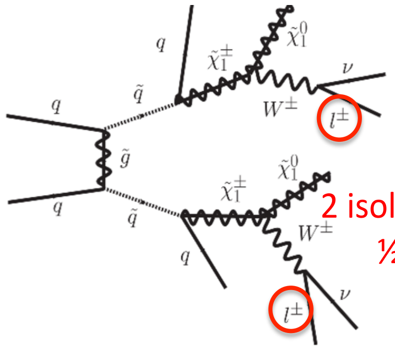




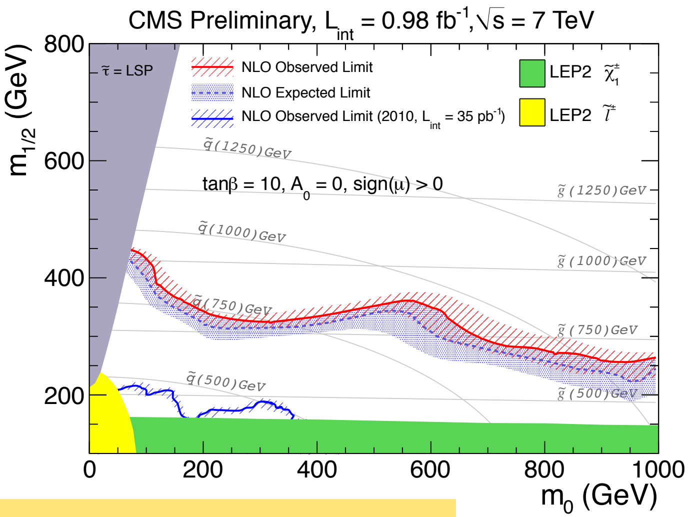
From data in CMS PAS SUS-11-017

Other Leptonic Analyses

- Same-sign di-leptons
  - Very small background

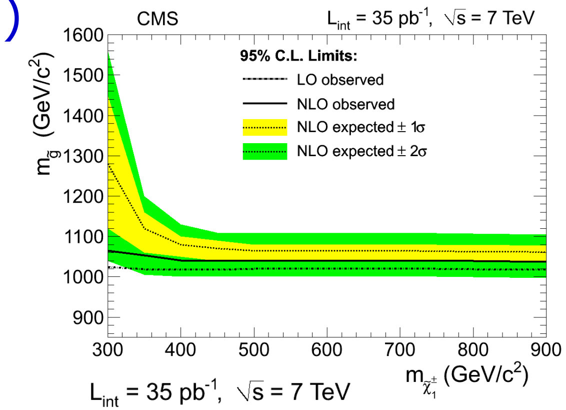


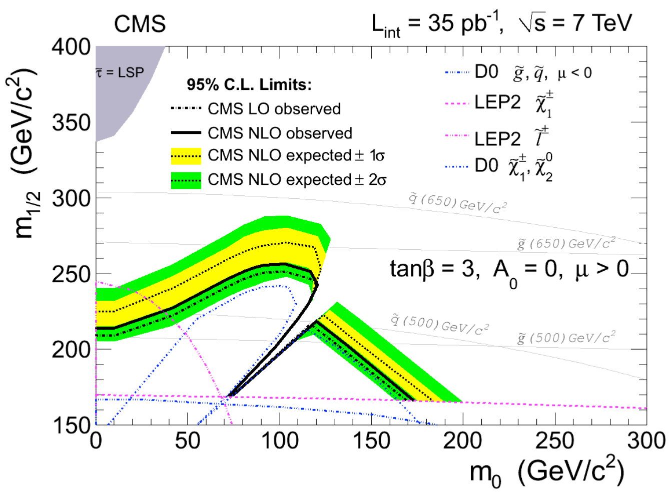
2 isolated leptons:
½ SS, ½ OS



arXiv:1104.3168
CMS PAS SUS-11-010

- Three or more leptons
  - Very small background, probes co-NLSP models (GMSM)





arXiv:1106.0933

Where we are ...

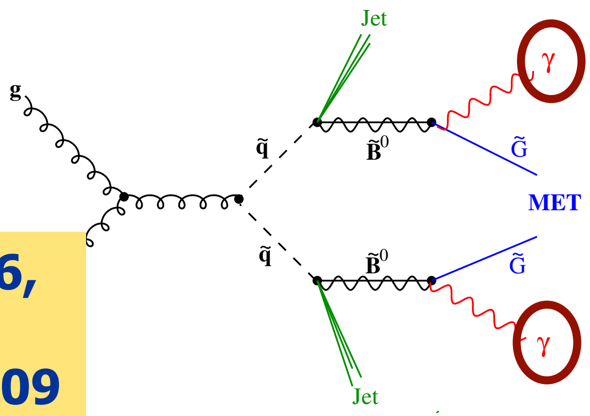
- The CMS Experiment
- Hadronic searches
- Leptonic searches
- **Searches with photons**
  → Search with di-photon
  → Searches with one photon

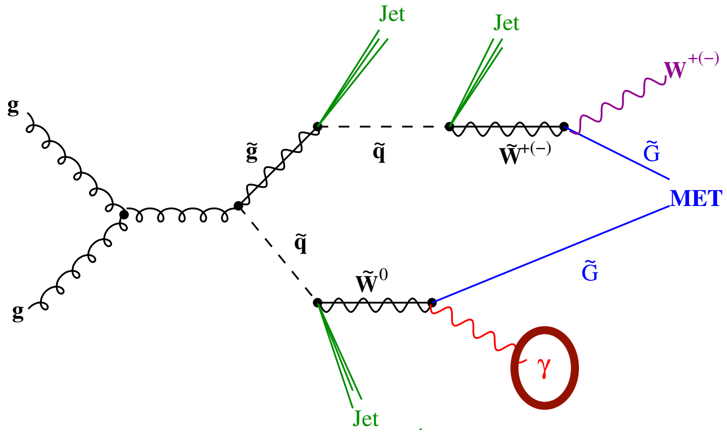
Searches with Photons: Introduction

In General Gauge Mediated SUSY

- Gravitino is LSP
- Neutralino is NLSP
  - Neutralinos: mix of Binos, neutral Winos, and Higgsinos
  - In CMS up to now: interpretation via a "Bino-like" neutralino model, with $\chi_0^1 \rightarrow \gamma + G$ (undetected $G \Rightarrow E_T^{miss}$)
  - Conserve R parity ⇒ two neutralinos ⇒ di-photon analysis
- NEW: Add simplified model where the Wino is less massive than the Bino, resulting in a neutralino-chargino co-NLSP
  - Photons not as common as in Bino-like case, but still occuring, most frequently at lower neutralino mass ⇒ single photon analysis

Phys. Rev. Lett. 106, 211802 (2011)
CMS PAS SUS-11-009





Searches with Photons: Event Selection

- **Di-photon analysis:**
  - At least 2 photons in barrel with $p_T^{\gamma 1} > 45$ GeV, $p_T^{\gamma 2} > 30$ GeV
  - At least 1 jet with $p_T > 30$ GeV, $|\eta|<2.6$
  - *Loose signal region:* $E_T^{miss} > 50$ GeV
  - *Tight signal region:* $E_T^{miss} > 100$ GeV

- **Single photon analysis:**
  - Exactly 1 photon in barrel with $p_T^{\gamma} > 75$ GeV (due to trigger constraint)
  - $H_T > 400$ GeV (also from trigger)
  - At least 3 jets with $p_T > 30$ GeV, $|\eta|<2.6$
  - $E_T^{miss} > 200$ GeV

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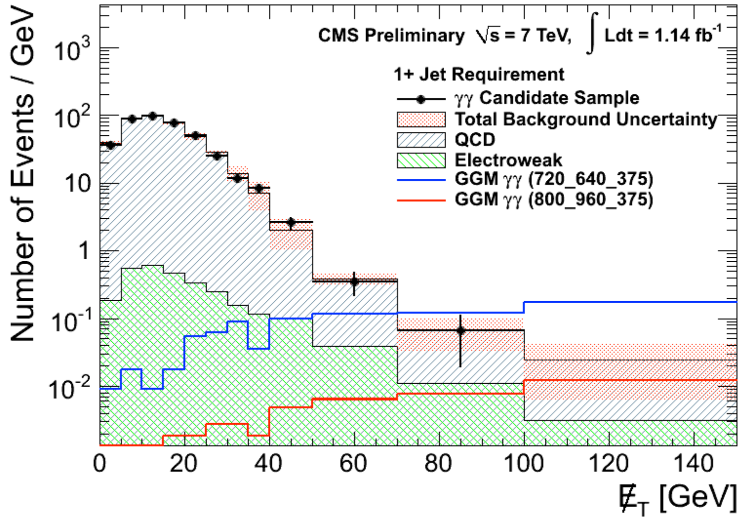
Searches with Di-Photons: Background Determination

- **QCD background (no true E_T^{miss})**
  - Mis-measurement of E_T^{miss} in QCD processes and/or photon mis-identification:
    - Direct di-photon production
    - γ+jets and multijets, with jets mimicking photons
  - Background determined from samples with 2 fake γ or 2 electrons

- **Electroweak background with true E_T^{miss}**
  - Background from events with real or fake photon and $W \rightarrow \nu e$ (where e is misidentified as γ)

- **Fake rate determination**
  - Measure rate of events in Z region in eγ and ee sample:

    $f_{e\rightarrow\gamma} = 0.014 \pm 0.0004$ (stat.) ± 0.002 (syst.)



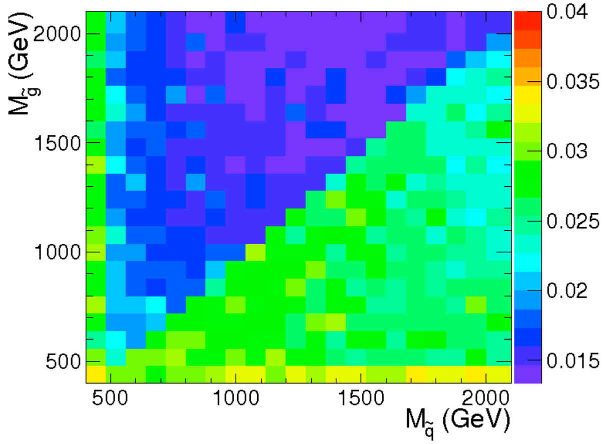
CMS PAS SUS-11-009

Searches with Di-Photons: Results

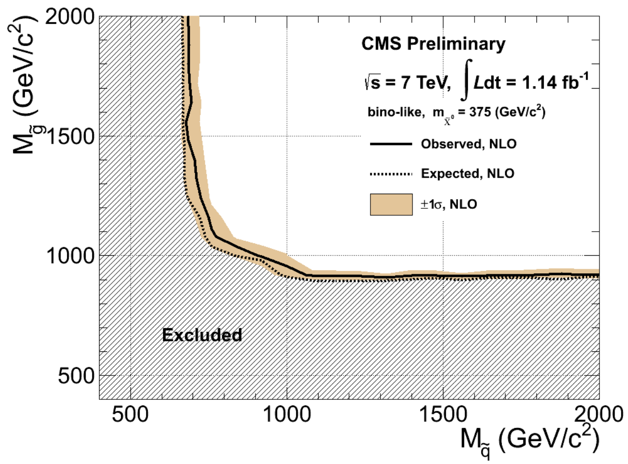
Sample	Loose selection ($E_T^{miss} > 50$ GeV)	Tight selection ($E_T^{miss} > 100$ GeV)
Total predicted SM	11.3 ± 1.9 ± 0.8	1.5 ± 0.8 ± 0.6
Data	9	0

No excess observed!

- 95% CL upper limits on the cross section in gluino-squark mass space for a neutralino mass of 375 GeV



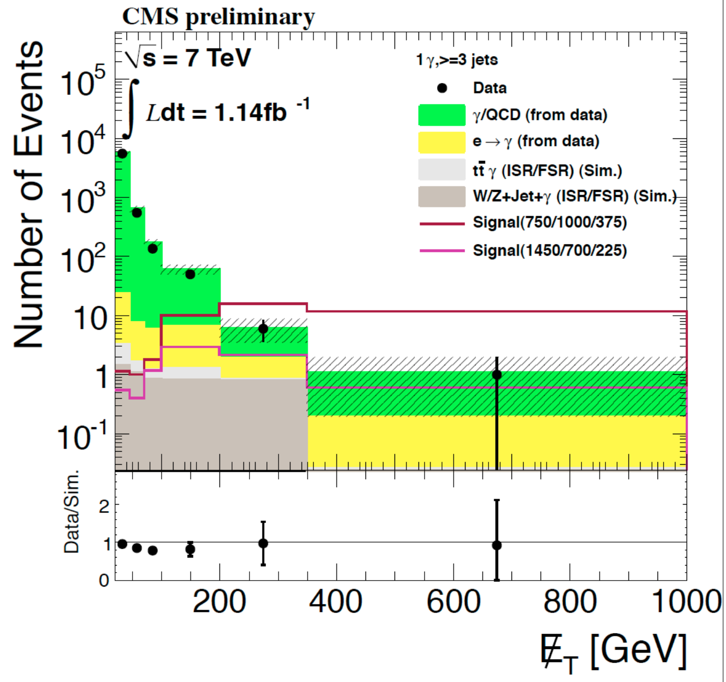
- 95% CL exclusion contours in gluino-squark mass space for a neutralino mass of 375 GeV



CMS PAS SUS-11-009

Searches with Single Photons: Background Determination

- Background determination similar to di-photon case
- Additional backgrounds: initial state radiation (ISR) and final state radiation (FSR) of photons:
  - ISR and FSR in events with electrons in final state covered by EW background prediction from data
  - Remaining contributions from SM process are very small – taken from Monte Carlo simulation with a systematic uncertainty of 100%.



Sample	Event yield	(stat.)	(syst.)
Data	7		
QCD (est. from data)	5.16	± 2.58	± 0.62
EWK $e \to \gamma$ (est. from data)	1.22	± 0.13	± 0.04
FSR/ISR ($W \to \mu/\tau\nu, Z \to \nu\nu$) (Sim.)	0.80	± 0.31	± 0.80
FSR/ISR ($t\bar{t} \to \mu/\tau\nu + X$) (Sim.)	0.07	± 0.05	± 0.07
Total SM background estimate	7.24	± 2.6	± 1.53

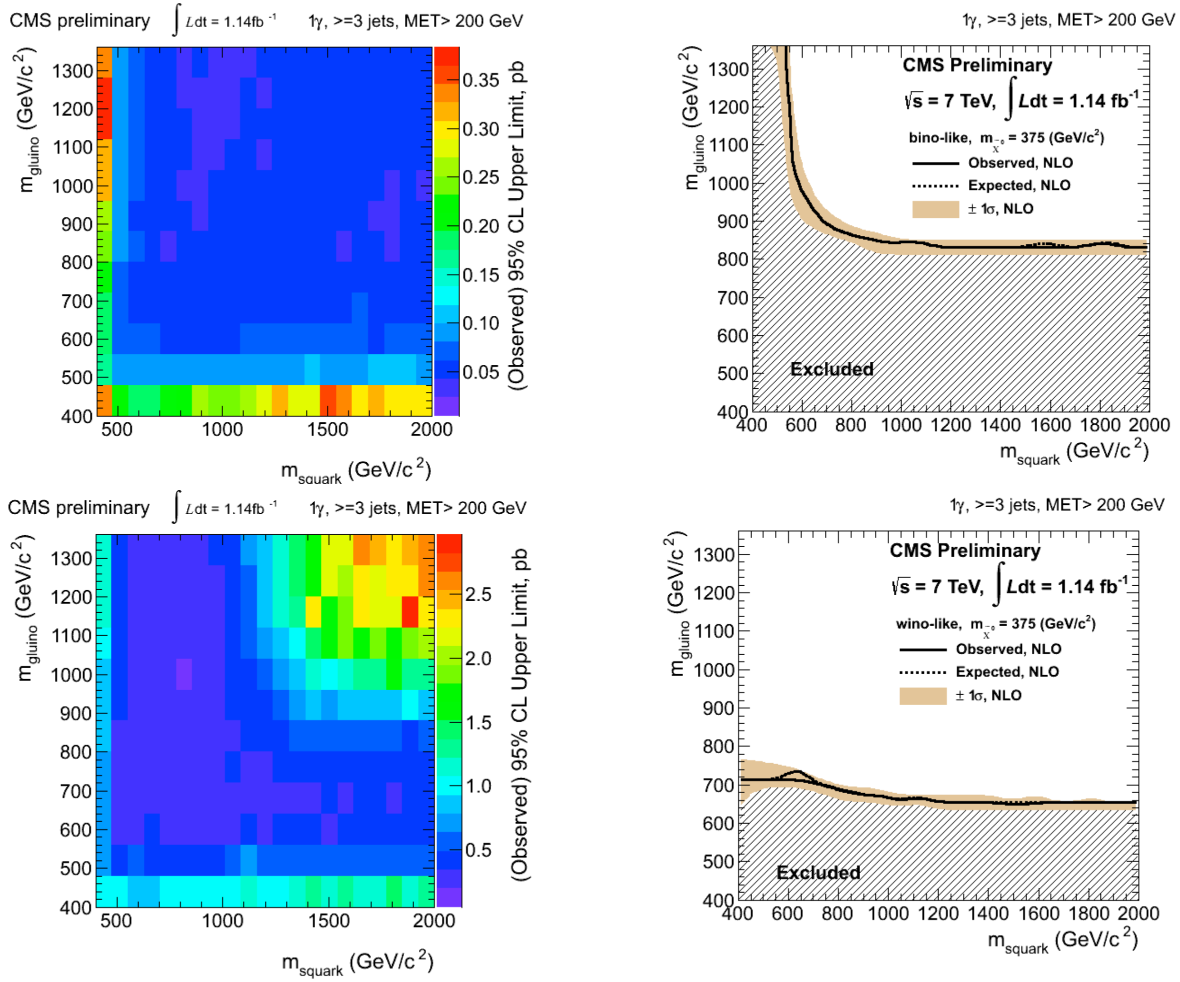
No excess observed!

CMS PAS SUS-11-009

Searches with Single Photons: Results

95% CL upper limit in gluino-squark mass space

95% CL exclusion contours in gluino-squark mass space



- Bino-like
- Wino-like

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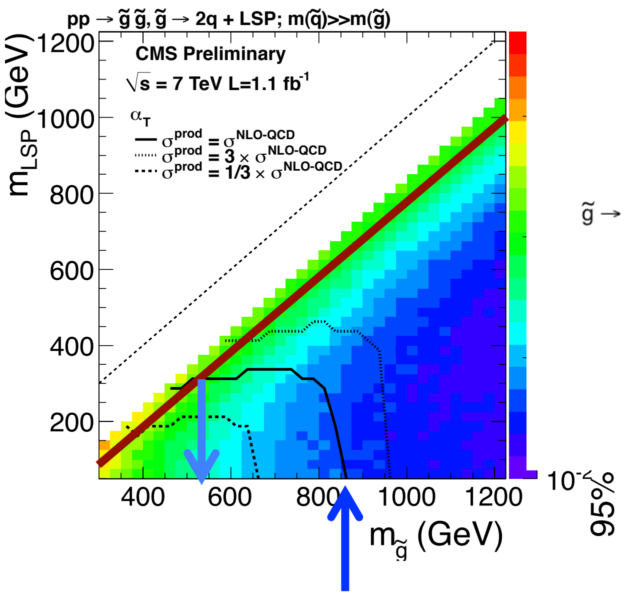
Summary: Interpretation with Simplified Models

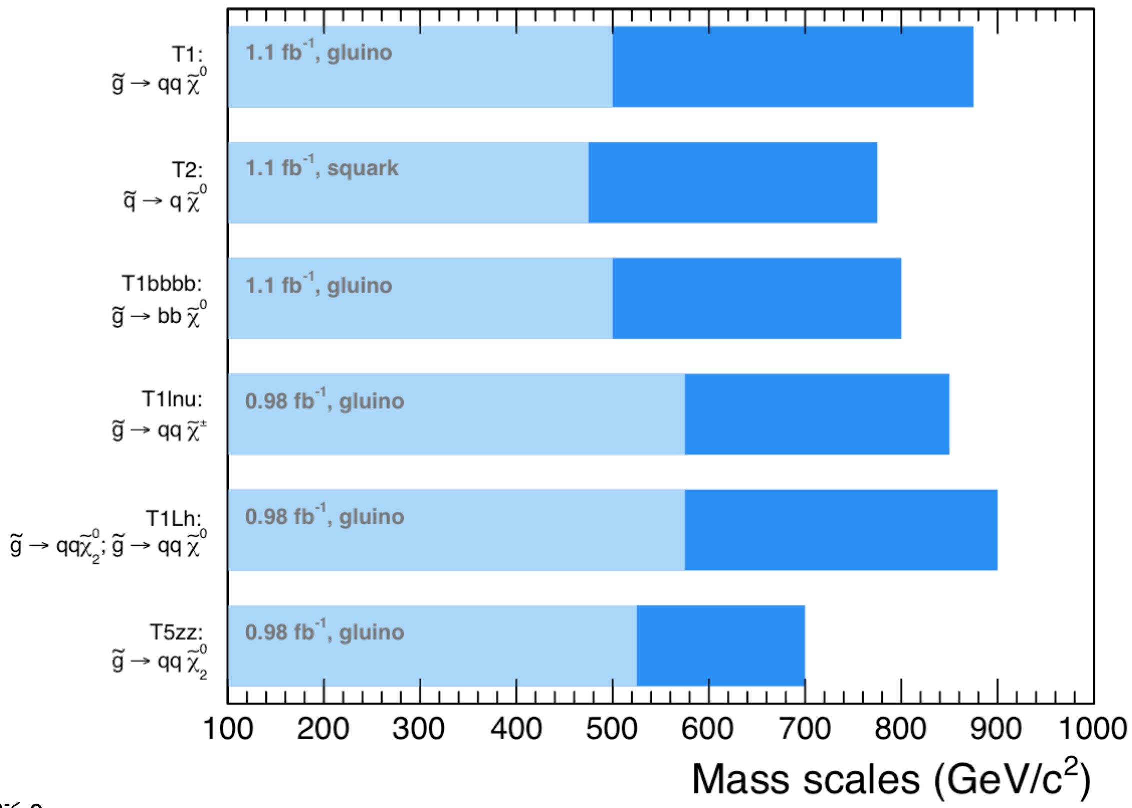
- For limits on m(gluino): m(squark)>>m(gluino) and vice verso

$$\sigma^{prod} = \sigma^{NLO\text{-}QCD}$$

$$m(\tilde{\chi}^{\pm}),\ m(\tilde{\chi}^0_2) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$$



Ranges of exclusion limits for gluinos and squarks, varying $m(\tilde{\chi}^0)$
CMS preliminary



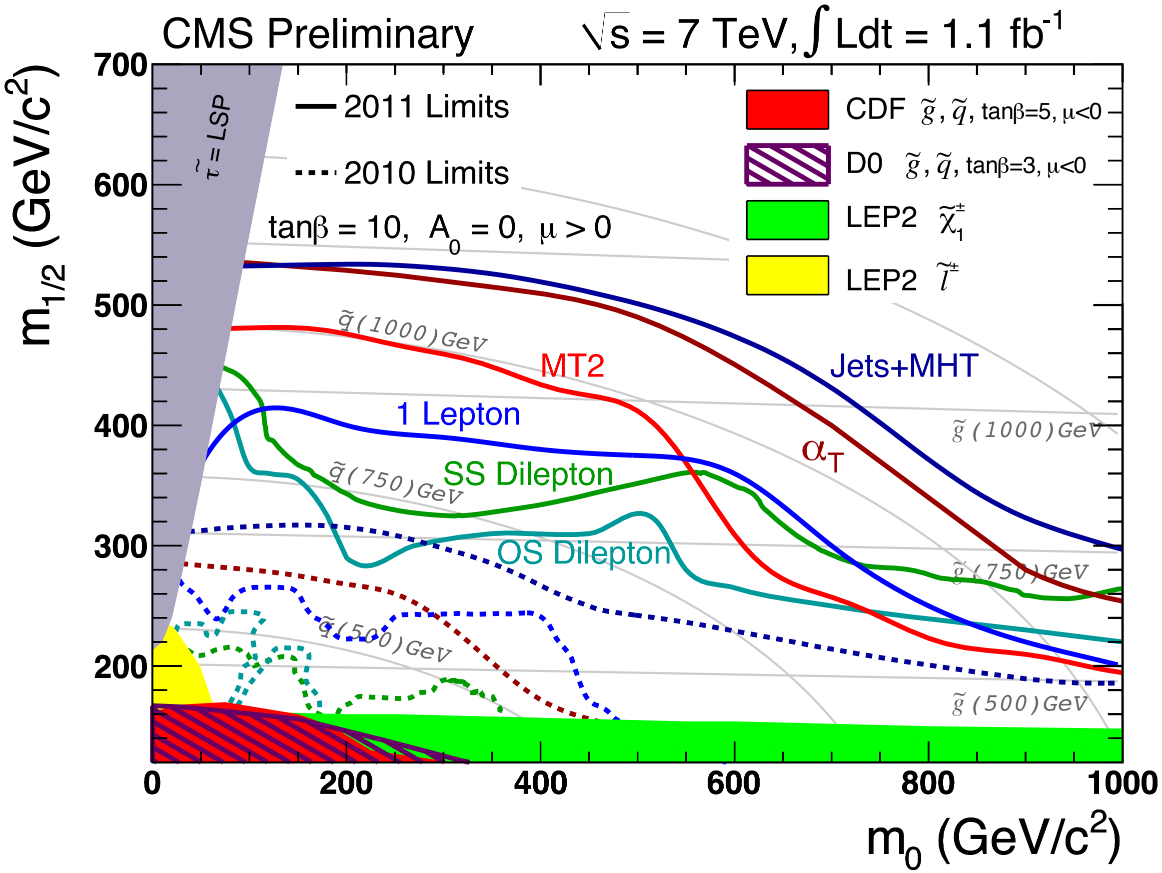
$m(\chi^0)$=m(gluino)-200GeV (light blue)

$m(\chi^0)=0$ (dark blue)

Summary and Outlook

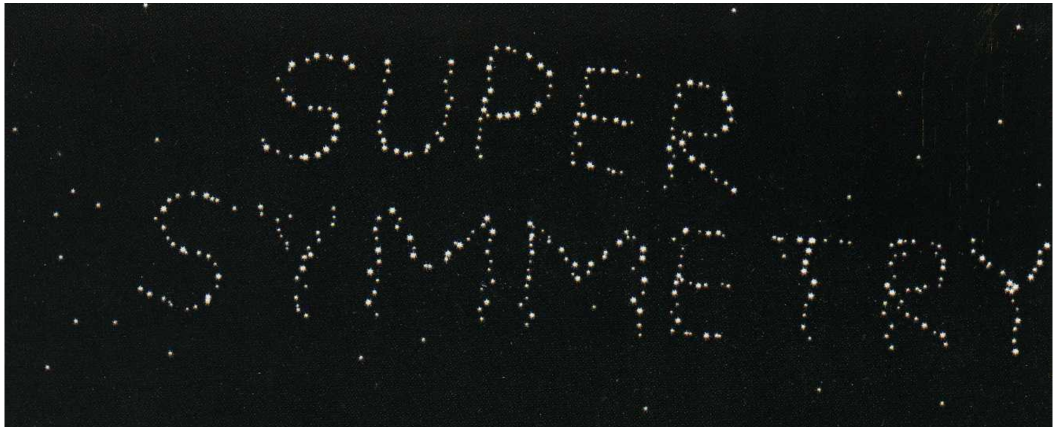
- Results from many analysis with 1 fb^{-1} have been presented
- None of the analysis have observed any significant deviation from the Standard Model ☹
- Exclusion limits have been set
  - Using CMSSM
  - In simplified models

Much more data to analyze – stay tuned!



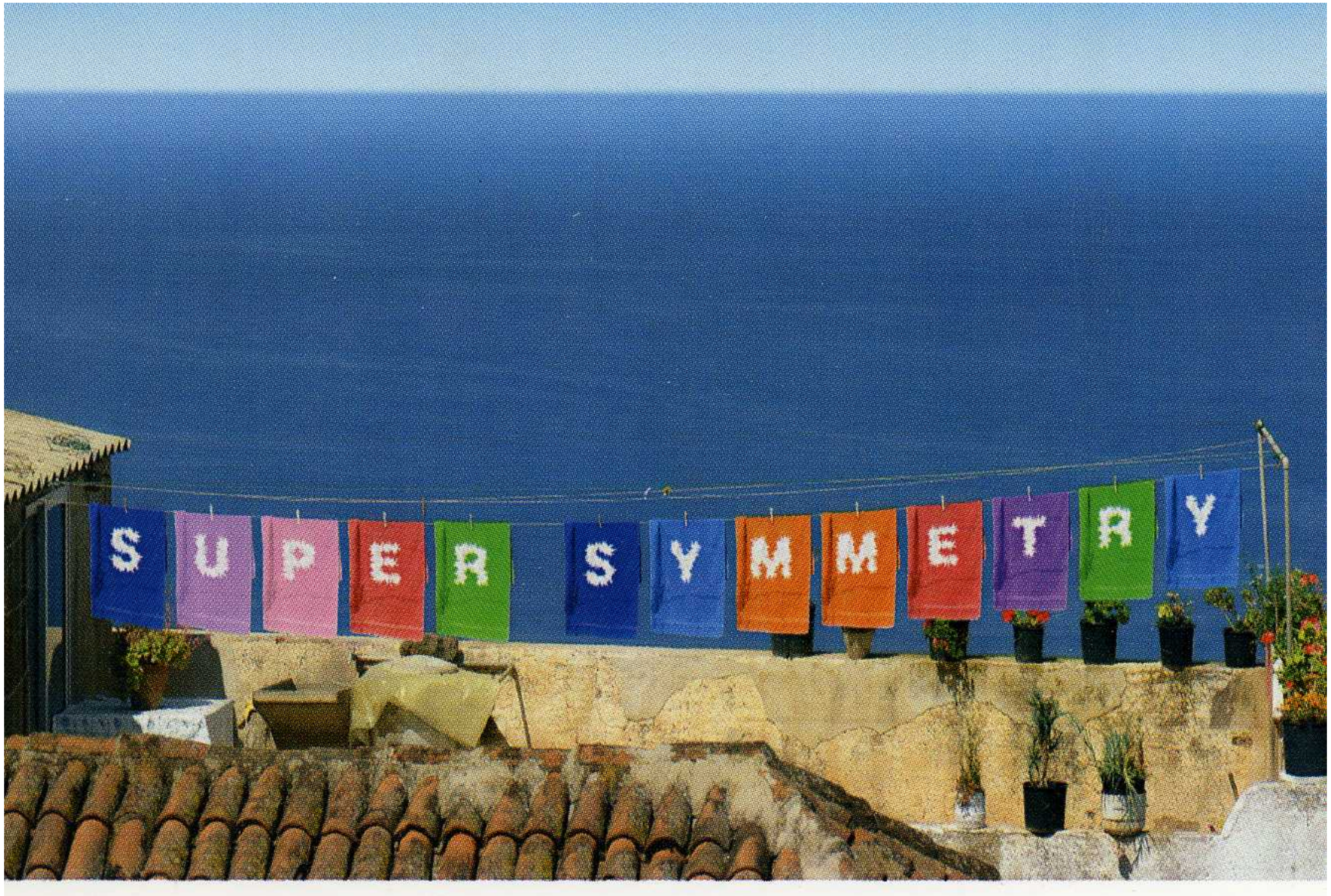
Analyses that are presented in parallel talks

- A Search for Supersymmetry Using Events with Photons and Large Missing Transverse Energy at CMS (Rachel Yohay)
- A Search for New Physics in Events with Jets and Missing Energy at CMS (Seema Sharma)
- Search for Squarks and Gluinos using Kinematic Variables at CMS (Edward Laird)
- Search for new physics with same-sign isolated dilepton events with jets and missing transverse energy at CMS (Frank Golf)
- Search for supersymmetry in events with multiple isolated leptons at CMS (Richard Carl Gray)
- Search for supersymmetry in final states with a lepton, jets and missing energy (Finn O'Neill Rebassoo)
- Interpretation of CMS searches for beyond-standard-model phenomena in the supersymmetry framework with simplified models (Mariarosaria D'Alfonso)



Thank you for listening

Backup slides follow…



All-Hadronic Search with M_{T2} Method: Background Estimation for QCD

High M_{T2} analysis:

- Factorization method with $\Delta\phi_{min}$ (azimuth angle between E_T^{miss} vector and closest jet) and M_{T2}
- Correlation between $\Delta\phi_{min}$ and M_{T2} is parameterized by

$$r(M_{T2}) = \frac{N(\Delta\Phi_{\min} \geq 0.3)}{N(\Delta\Phi_{\min} \leq 0.2)} = \exp(a - b \cdot M_{T2}) + c$$

- First validated on MC, then measured with data in the region 50 GeV < M_{T2} < 80 GeV
- Extrapolation to M_{T2} > 400 GeV gives the number of bg events
- Conservative uncertainty of 100% assigned

Low M_{T2} analysis:

- Estimated similar as for high M_{T2} analysis on pre-b-tagged sample to have enough statistics

  (Ratio of b-tagged/pre-b-tagged sample constant vs. M_{T2})

CMS PAS SUS-11-005

Opposite Sign Di-Leptons: Results from Counting Experiments

Table 2: Summary of the observed and predicted yields in the 2 signal regions. The uncertainty in the MC prediction is statistical only. The systematic uncertainties on the ABCD′ and $p_T(\ell\ell)$ method predictions are discussed in the text. The background yield N_{bkg} is the error-weighted average of the 2 data-driven predictions. The non-SM yield UL is a CL_S 95% confidence level upper limit. The LM1, LM3 and LM6 yields include uncertainties from MC statistics, trigger efficiency, lepton selection efficiency, hadronic energy scale and integrated luminosity.

	high E_T^{miss} signal region	high H_T signal region
observed yield	8	4
MC prediction	7.3 ± 2.2	7.1 ± 2.2
ABCD′ prediction	4.0 ± 1.0 (stat) ± 0.8 (syst)	4.5 ± 1.6 (stat) ± 0.9 (syst)
$p_T(\ell\ell)$ prediction	14.3 ± 6.3 (stat) ± 5.3 (syst)	10.1 ± 4.2 (stat) ± 3.5 (syst)
N_{bkg}	4.2 ± 1.3	5.1 ± 1.7
non-SM yield UL	10	5.3
LM1	49 ± 11	38 ± 12
LM3	18 ± 5.0	19 ± 6.2
LM6	8.1 ± 1.0	7.4 ± 1.2

Table 3: Summary of the opposite-flavor subtraction results. The quantity Δ is defined in Eq. 4. The CL_S 95% CL upper limit on this quantity, as well as the predicted values in the LM1, LM3 and LM6 scenarios, are also summarized. The LM1, LM3 and LM6 uncertainties are from MC statistics, trigger efficiency, lepton selection efficiency, hadronic energy scale and integrated luminosity.

	high E_T^{miss} signal region	high H_T signal region
observed Δ	3.6 ± 2.9 (stat) ± 0.4 (syst)	-0.9 ± 1.8 (stat) ± 1.1 (syst)
UL	7.9	3.6
LM1	27 ± 6.0	24 ± 7.6
LM3	3.2 ± 0.9	3.3 ± 1.1
LM6	2.0 ± 0.2	1.9 ± 0.3

Opposite Sign Di-Leptons: Results from Counting Experiments

Table 4: Summary of model-dependent limits. The efficiency and acceptance are defined in the text; the efficiency uncertainty is dominated by the uncertainty in the hadronic energy scale. The CL_S 95% CL UL on the quantity $\sigma \times A$ is indicated, as well as the value of this quantity for the LM1, LM3 and LM6 scenarios.

	LM1	LM3	LM6
high E_T^{miss} signal region			
efficiency (%)	45 ± 10	41 ± 11	52 ± 6
acceptance (%)	1.6	0.84	3.3
UL($\sigma \times A$) (fb)	25	28	20
$\sigma \times A$ (fb)	108	43	16
high H_T signal region			
efficiency (%)	42 ± 13	38 ± 12	50 ± 7
acceptance (%)	1.2	0.85	3.0
UL($\sigma \times A$) (fb)	15	17	12
$\sigma \times A$ (fb)	83	46	15

CMSSM

Simplest ansatz: CMSSM – assume universality at high energy scale

- Universal scalar masses: $m^2 \cong m_0^2$
- Universal gaugino masses: $M_i = m_{1/2}$ ("GUT relation")
- Universality of soft-breaking trilinear terms:

$$\mathcal{L}_{\mathrm{tri}} = A_0(H_U Q y_u \bar{u} + H_D Q y_d \bar{d} + H_D L y_l \bar{e})$$

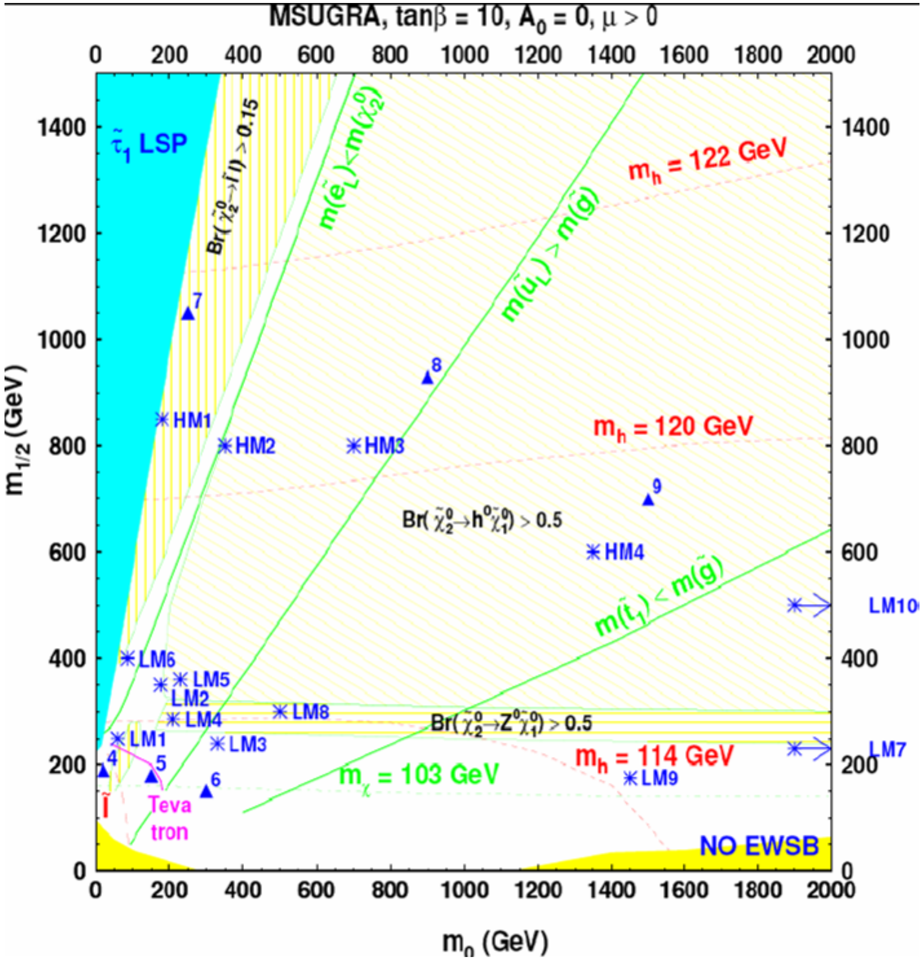
- Results in **five** parameters, if possible phases are ignored:
  $m_0^2, m_{1/2}, A_0, b, \mu$
- Require correct value of M_z,
  → $|\mu|$, b given in terms of tan $\beta = v_u/v_d$ and sign μ

➔ CMSSM parameters:
$m_0^2, m_{1/2}, A_0$, tan β, sign μ

CMS Benchmark Points

Interesting for our nearer future are the Low Mass (LM points)
The High Mass (HM) points are close to the ultimate LHC reach…

Model	Cross Section (pb)	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0	$\tan\beta$
LM0	110	200	160	-400	10
LM1	16.06	60	250	0	10
LM2	2.42	185	350	0	35
LM3	11.79	330	240	0	20
LM4	6.70	210	285	0	10
LM5	1.94	230	360	0	10
LM6	1.28	85	400	0	10
LM7	2.90	3000	230	0	10
LM8	2.86	500	300	-300	10
LM9	11.58	1450	175	0	50



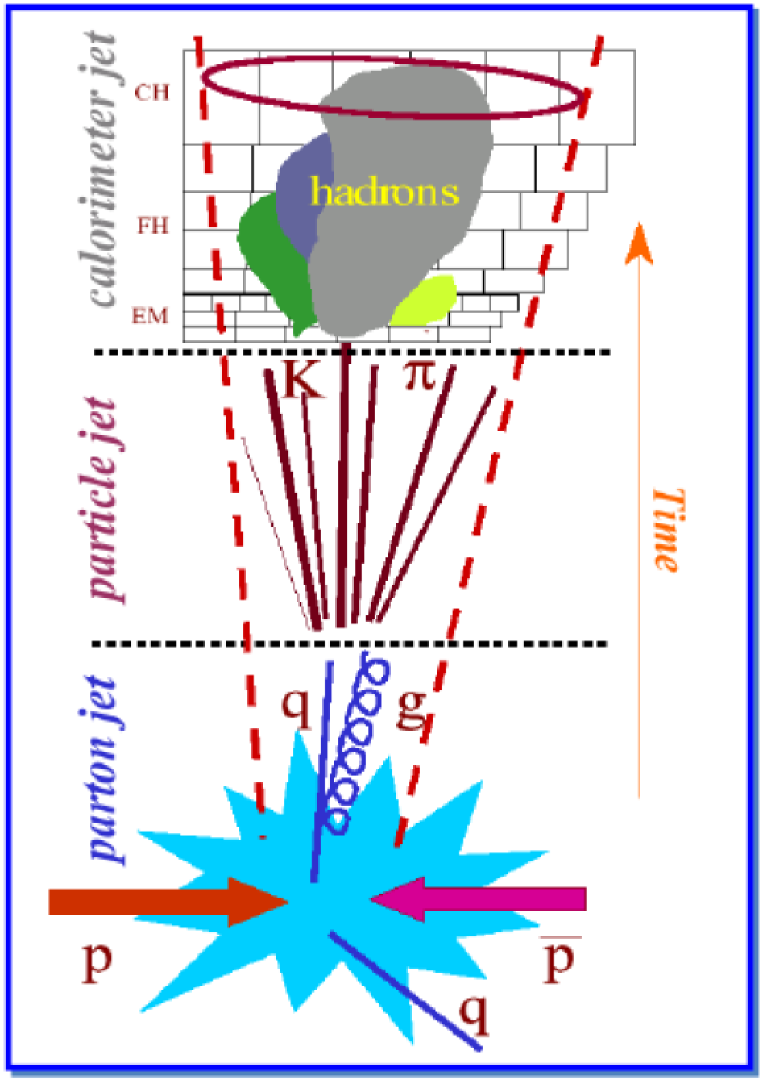
CMS Benchmark Point Characteristics

- **Point LM1 :**
  - Same as post-WMAP benchmark point B' and near DAQ TDR point 4.
  - M(gluino) > M(squark), hence gluino -> squark+quark is dominant
  - B(X02 -> slep_R lept) = 11.2%, B(X02 -> stau_1 tau) = 46%, B(X+1 -> sneut_L lept) = 36%
- **Point LM2 :**
  - Same as post-WMAP benchmark point I'.
  - M(gluino) > M(squark), hence gluino -> squark+quark is dominant (sbot1+b is 25%)
  - B(X02 -> stau_1 tau) = 96%, B(X+1 -> stau_1 nu) = 95%
- **Point LM3 :**
  - Same as NUHM point gamma and near DAQ TDR point 6.
  - M(gluino) < M(squark), hence gluino -> squark+quark is forbidden except B(gluino -> sbot1,2 bot) = 85%
  - decays: B(X02 -> lept lept X01) = 3.3%, B(X02 -> tau tau X01) = 2.2%, B(X+1 -> W+ X01) = 100%
- **Point LM4 :**
  - Near NUHM point alpha in on-shell Z0 decay region.
  - M(gluino) > M(squark), hence gluino -> squark+quark is dominant with B(gluino -> sbot1 bot) = 24%
  - decays: B(X02 -> Z0 X01) = 97%, B(X+1 -> W+ X01) = 100%
- **Point LM5 :**
  - In h0 decay region, same as NUHM point beta.
  - M(gluino) > M(squark), hence gluino -> squark+quark is dominant with B(gluino -> sbot1 bot) = 19.7% and B(gluino -> stop1 top) = 23.4%
  - decays: B(X02 -> h0 X01) = 85%, B(X02 -> Z0 X01) = 11.5%, B(X+1 -> W+ X01) = 97%

CMS Benchmark Point Characteristics (2)

- **Point LM6 :**
  - Same as post-WMAP benchmark point C'.
  - M(gluino) > M(squark), hence gluino -> squark+quark is dominant
  - B(X02 -> slepL lept) = 10.8%, B(X02 -> slepR lept) = 1.9%, B(X02 -> stau1 tau) = 14%, B(X+1 -> sneut lept) = 44%
- **Point LM7 :**
  - Very heavy squarks, outside reach, but light gluino.
  - M(gluino) = 678 GeV, hence gluino -> 3-body is dominant
  - B(X02 -> lept lept X01) = 10%, B(X+1 -> lept nu X01) = 33%
  - EW chargino-neutralino production cross-section is about 73% of total.
- **Point LM8 :**
  - Gluino lighter than squarks, except sbot1 and stop1.
  - M(gluino) = 745 GeV, M(stop1) = 548 GeV (A0 = -300), gluino -> stop1+t is dominant
  - B(gluino -> stop1+t) = 81%, B(gluino -> sbot1+b) = 14%, B(squarkL -> q+X02) = 26-27%,
  - B(X02 -> Z0 X01) = 100%, B(X+1 -> W+ X01) = 100%
- **Point LM9 :**
  - Heavy squarks, light gluino. Consistent with EGRET data on diffuse gamma ray spectrum, WMAP results on CDM and MSUGRA (see W. de Boer et al., astro-ph/0408272 v2). Similar to LM7.
  - M(gluino) = 507 GeV, hence gluino -> 3-body is dominant
  - B(X02 -> lept lept X01) = 6.5%, B(X+1 -> lept nu X01) = 22%
- **Point LM10 :**
  - Similar to LM7, but heavier gauginos.
  - Very heavy squarks, outside reach, but lighter gluino.
  - M(gluino) = 1295 GeV, hence gluino -> 3-body is dominant
  - B(gluino> -> t tbar X04) = 11%, B(gluino -> t b X+2) = 27%

Jets

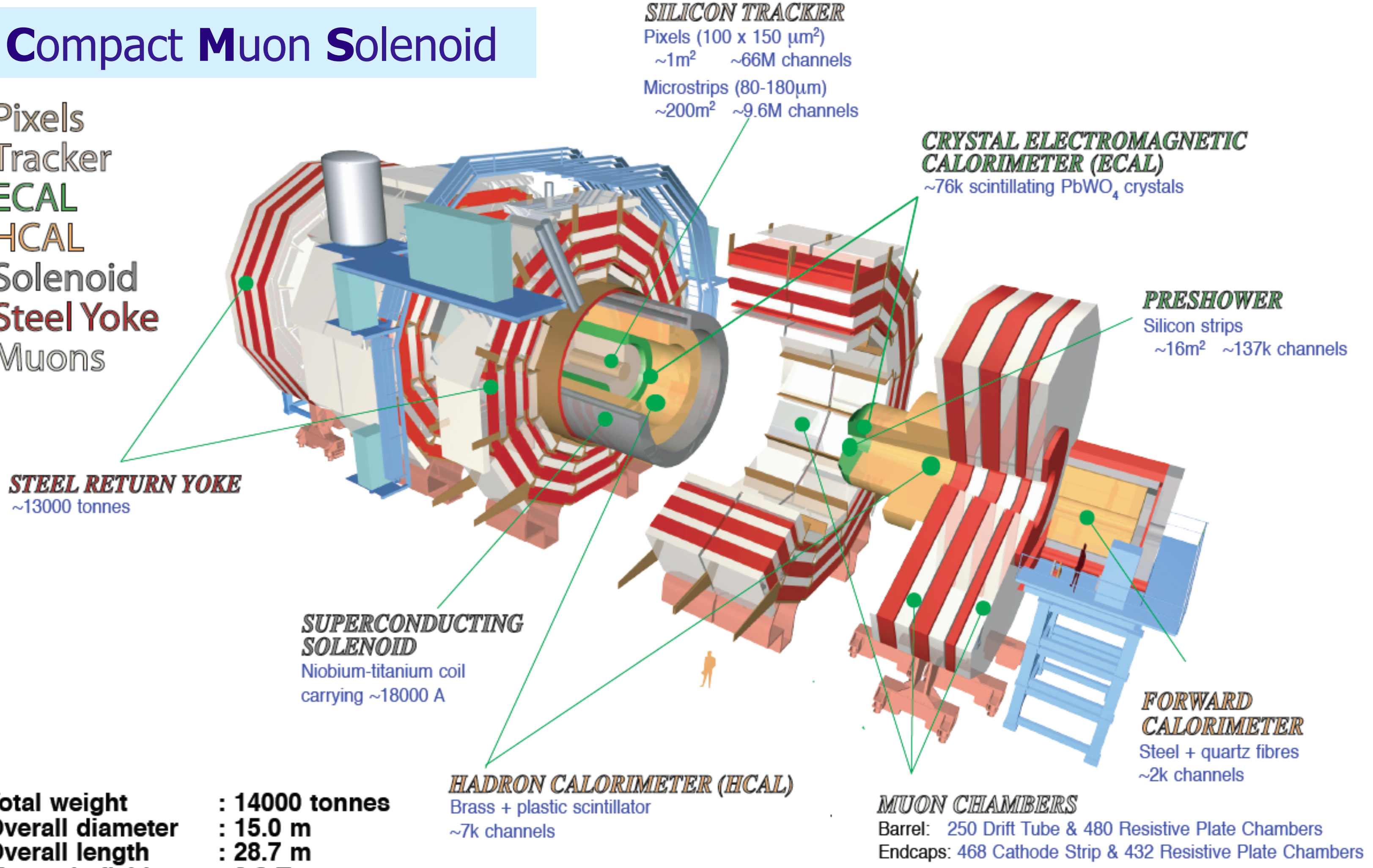


calorimeter jet
CH
FH
EM
hadrons
particle jet
K
π
parton jet
q
g
Time
p
p̄
q

CMS

Compact Muon Solenoid

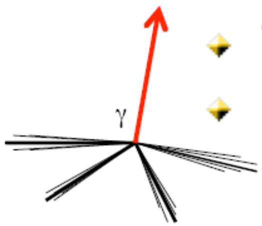
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons

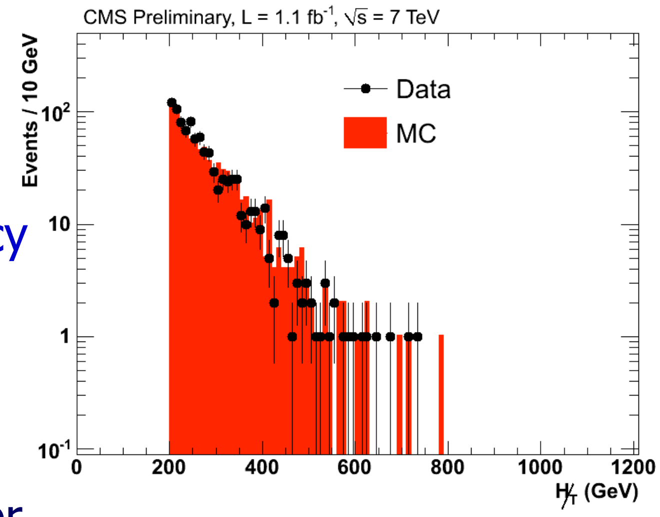


Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Inclusive All-Hadronic Search: Background Estimation for Z → νν

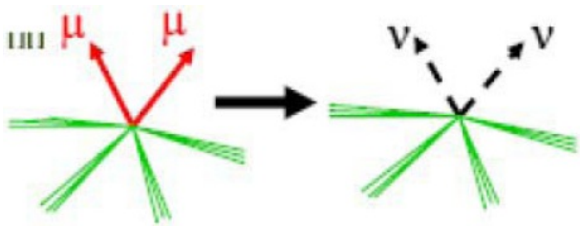
- **Background estimation with γ+jets :**
- Strategy:
  - Declare photon invisible to emulate neutrinos
  - Then re-calculate E_T^{miss} for this event
  - Correct for the photon reconstruction efficiency and neutrino branching ratio





SUSY signals could bias the prediction (depending on the SUSY scenario, more for Z→μμ+jets (mSUGRA) or γ+jets (GMSB))

→ Useful to have background estimations from different processes, preferably Z→μμ+jets:
  - Production mechanisms are the same in both processes → E_T^{miss} is correctly estimated without having to rely on Monte Carlo simulations
  - Drawback: too low statistics, but comparable result in baseline selection



CMS PAS SUS-11-004

Interesting Variables: M_T

M_T is used for single-leptonic analyses:

- Measure of the transverse invariant mass of the lepton and the missing momentum (with $\Delta\Phi$: angle between lepton and E_T^{miss})

$$M_T^2 = 2 p_T^{\text{lepton}} E_T^{miss} \left(1 - \cos \Delta\Phi\right)$$

- For an event containing a single $W \rightarrow \mu \nu$ decay,
  $M_T^2 = (p(\mu) + p(\nu))^2 = M_W^2$

  Single $W \rightarrow \mu\ \nu$ decays appear as peak with sharp falling edge close to the W mass

→ If a W decay is the source of both the lepton and the E_T^{miss}, the requirement $M_T > M_W$ would remove most of the SM events

- But: this cut also removes a significant fraction of the SUSY events!
- Need to combine with another cut…

Background determination for α_T: H_T vs $|\eta|$ of leading Jet

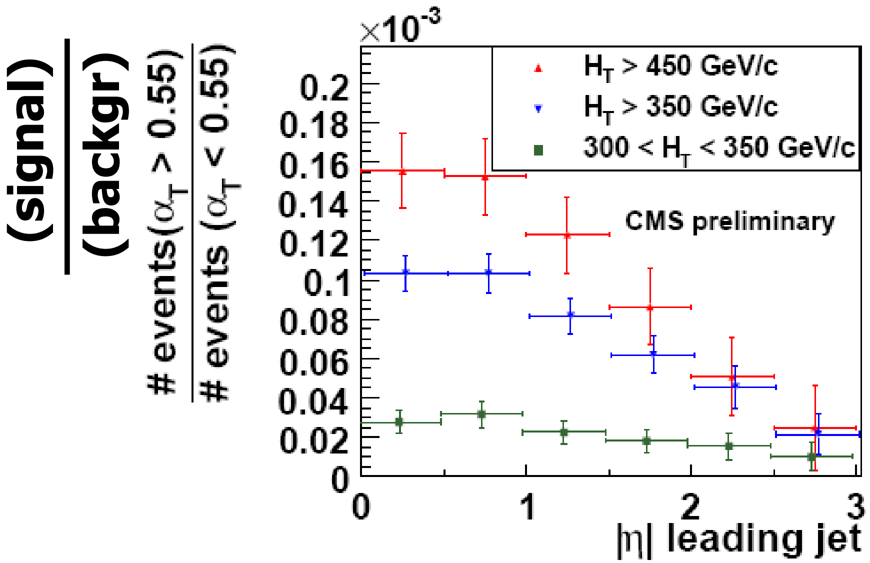
Try to understand the background for α_T:

- SUSY signal is expected to be more central and in higher H_T region ($H_T = \Sigma E_T^{jets}$)
- Background relatively flat in $|\eta|$ and H_T

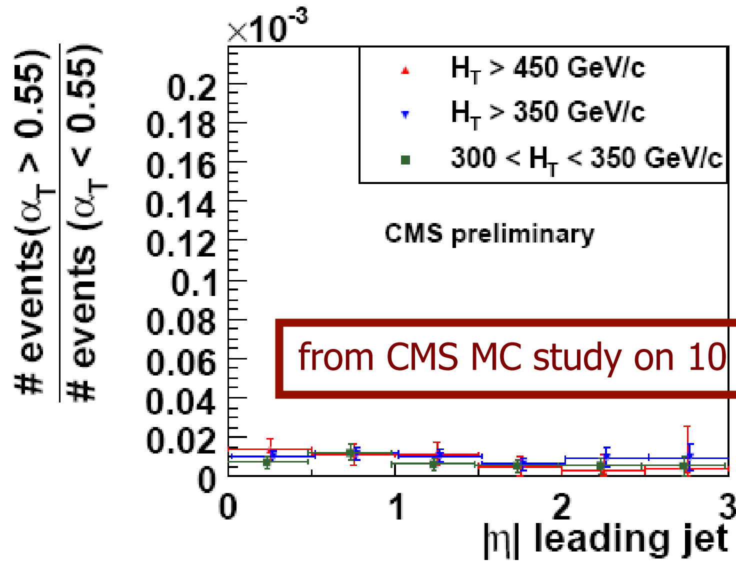
→ Can lower H_T region be used to extrapolate background expectation to higher H_T values?

→ Check behavior for both α_T regions (signal and bg region):

SM+SUSY (LM0)



SM only



from CMS MC study on 10 TeV 2009

Reconstructed Objects

- You can reconstruct so called "physics objects":
  - Photons: no track but energy in el-m (and not in the hadronic) calorimeter
  - Electrons: track and energy in el-m (and not in the hadronic) calorimeter
  - Muons: track in inner tracker and muon chamber
  - Jets: cluster in hadronic calorimeter
  - Missing transverse energy (if transverse energy sum is not 0)

- Of course reconstruction is not always simple
- Different reconstruction algorithms for each object are on the market – need to choose the best one for each analysis

- Based on these objects we can select our SUSY events…

Pseudorapidity

- **Rapidity** of a particle of momentum $p=(E,0,0,p_z)$ is defined to be

  $y = ½ \log ((E+p_z)/(E-p_z))$

  Advantage: the rapidity difference is invariant under the longitudinal boost

- For massless particles, $p_z = E \cos \theta$, (θ : polar angle)

→ $y = ½ \log((1+\cos \theta)/(1-\cos \theta))$
$= \log (\cot (\theta/2))$
$= \eta$: pseudo-rapidity

Interesting Observables: E_T^{miss}

- Missing E_T: vector sum of the transverse energy deposited in all calorimeter cells (this combines, ideally, the momenta of all photons, electrons, hadronically decaying taus, and jets) and adding to this the transverse momenta of any muons, whose energy is measured using the muon detection system

$$\vec{p}_T^{\,\text{miss}} = -\left(\sum_{\text{calo towers}} \vec{p}_T - \sum_{\text{muons}} \vec{p}_T^{\,\text{deposited in calo towers}} + \sum_{\text{muons}} \vec{p}_T^{\,\text{tracker}} \right)$$

- The magnitude of the resultant vector is the missing E_T:

$$E_T^{\text{miss}} = \left| \vec{p}_T^{\,\text{miss}} \right|$$

Attention:

E_T^{miss} might be polluted by detector effects!

Interesting Observables: H_T^{miss}

- Analog to E_T^{miss}, but using jets above a certain jet threshold only:

$$H_T^{\mathrm{miss}} = \left| -\sum_i \vec{p}_T^{\,\mathrm{j_i}} \right|$$

Attention:

- You might have a cut on jet momentum of e.g. p_T>50 GeV
- But there might be several jets below that threshold which could still lead to a considerable amount of ignored momentum in the event!
- One idea to control this: add cut on ratio R with

$$R\left(H_T^{miss}\right) = \frac{H_T^{miss}\left(\text{selected jets with } p_T > 50\,\text{GeV}\right)}{H_T^{miss}\left(\text{all jets with } p_T > 30\,\text{GeV}\right)}$$

(numbers are just examples)

Interesting Observables: α_T

- α is a variable developed for 2-jet events:

$$\alpha = \frac{E_T^{\mathrm{j2}}}{M_{inv}^{\mathrm{j1,j2}}}$$

L. Randall and D. Tucker-Smith, arXiv:0806.1049.

→ Exactly 0.5 for perfectly measured QCD event

→ In addition, as the E_T of the second energetic jet enters in the numerator, uncertainties introduced through energy mis-measurements partly cancel out in α (if one of the two jet energies is measured wrong by a large amount the order of the two jets will be swapped)

- You can also use the transverse mass:

$$M_T^2 = 2 p_T^{\mathrm{lepton}} E_T^{miss} \left(1 - \cos\Delta\Phi\right)$$

- For massless particles (with $\Delta\Phi$ = difference in azimuthal angle of the jets):

$$\alpha_{\mathrm{T}} = \frac{E_T^{\mathrm{j2}}}{{M_{inv}^{\mathrm{j1,j2}}}_T}$$

$$\alpha_{\mathrm{T}} = \frac{E_T^{\mathrm{j2}}}{\sqrt{2E_T^{\mathrm{j1}}E_T^{\mathrm{j2}}\left(1-\cos\Delta\phi\right)}} = \frac{\sqrt{E_T^{\mathrm{j2}}/E_T^{\mathrm{j1}}}}{\sqrt{2\left(1-\cos\Delta\phi\right)}}$$

Interesting Observables: α_T (2)

Now extend α_T to n-jet events:

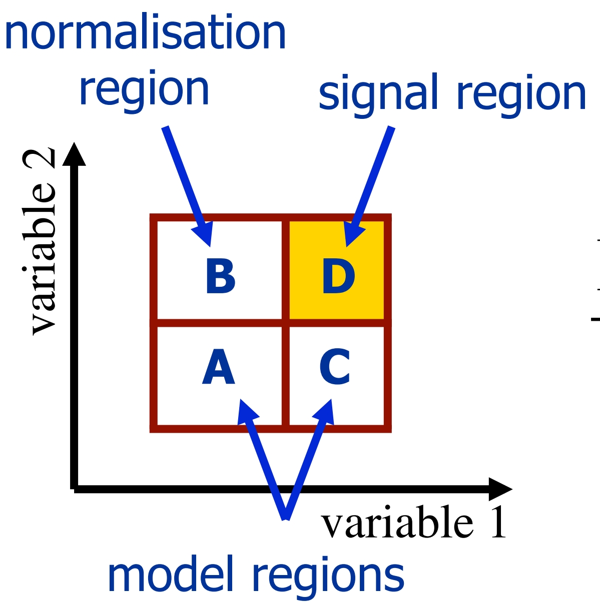
- Two pseudo jets are formed which balance each other as good as possible in the "pseudo-jets" $H_{T1} = \Sigma E_{Ti}$ and $H_{T2} = \Sigma E_{Tj}$ (E_{Ti} and E_{Tj}: transverse energies of the jets within a pseudo jet)
- Assuming massless jets, one can write:

$$\alpha_{\mathrm{T}} = 0.5\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - {H_T^{miss}}^2}}, \quad \text{with } \Delta H_T = H_{T1} - H_{T2}$$

$$\alpha_{\mathrm{T}} = 0.5\frac{1 - \Delta H_T / H_T}{\sqrt{1 - {H_T^{miss}}^2 / H_T^2}}$$

Factorisation (ABCD) Method

- Straightforward method, if two variables are uncorrelated:



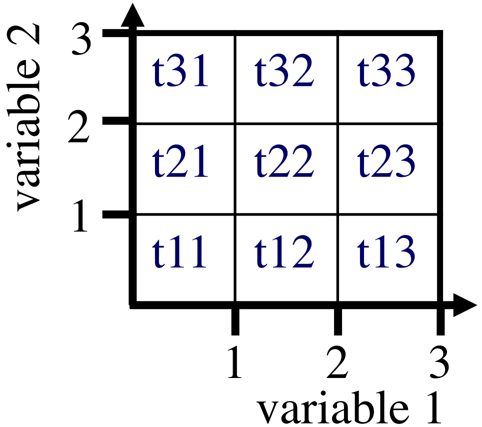
$$\frac{D}{C} = \frac{B}{A}$$

- Estimate number of background events in signal region: D=C·B/A

- Attention:
  - most variables are correlated
  - signal can be spilled into the normalisation region

Prediction from Templates

- Collect QCD events with topologies similar to signal events
- Fill variable to investigate of QCD event in 2-dim matrix



- Then measure the corresponding variables for your signal candidate event, and extract the predicted value for the background from template for this bin

Example for Prediction from Templates: Artificial E_T^{miss}

Missing transverse energy can have several artificial sources:

- Instrumental effects
- Software
- Collision or non-collision backgrounds
- Some effect you haven't yet thought of…

Predict these effects from data with templates!

→ Fill measured E_T^{miss} of collected QCD events in 2-dim matrix (e.g. with variable1=N_{jet}, variable2=H_T, which is expected to be less polluted by artificial effects)

→ Then measure these variables for your signal candidate event, and extract the E_T^{miss} template for this bin

Sounds straight forward, but attention:

- H_T of QCD events lower than expected for SUSY
  → need extrapolation
- QCD and signal events might be triggered by different (and differently efficient) triggers

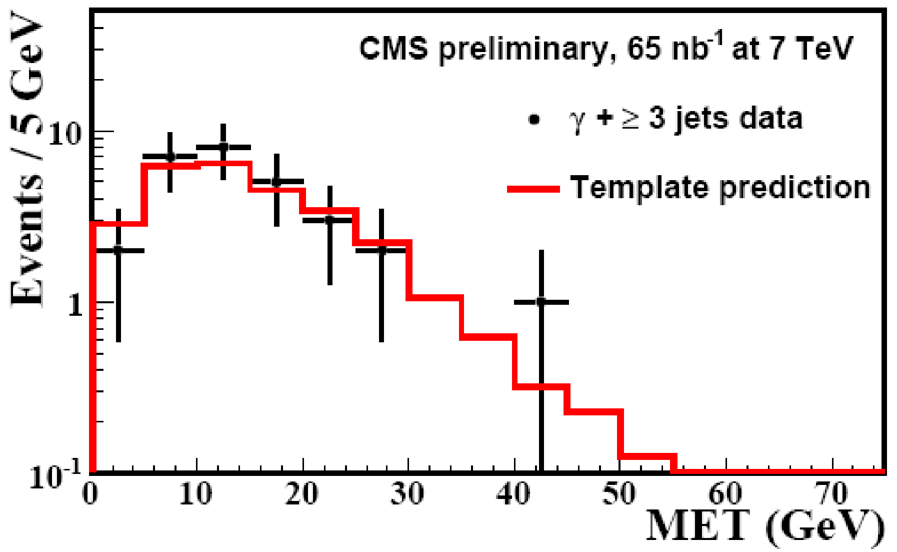
Example for Prediction from Templates: Artificial E_T^{miss}(2)

How can we check that it works with early data?

Predict the E_T^{miss} for γ+jets events using QCD jets:

→ Prediction quite good, given that:

- Photon sample expected to be polluted by neutral pions
- Jet energy scale for jets less well measured than the photon
- Different triggers used for the two data samples



Jet Smearing – Gaussian Part

Idea: Generate the **Gaussian** response function either with well measured dijet or with γ+jet events:

- In case of γ+jet events (photon well measured):
  - Use transverse momentum conservation in γ+jet events to calculate Gaussian response of calorimeters to jets from the distribution of the photon-jet p_T balance (with events containing exactly 1 jet):

$$R_1 = 1 + \frac{p_T^{miss} \cdot p_T^{\gamma}}{\left| p_T^{\gamma} \right|^2}$$

  - Measure this distribution in bins of p_T^{γ}

Jet Smearing – Gaussian Part (2)

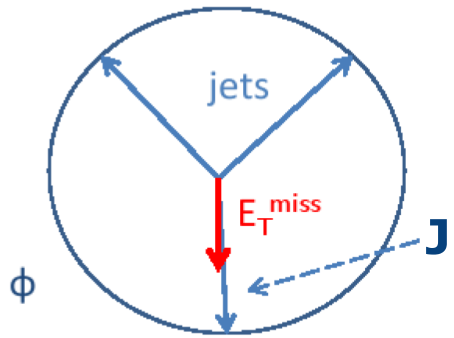
- In case of dijet events:
  - Apply jet smearing with the Gaussian jet response on low E_T^{miss}, well measured, dijet seed events
  - This produces a set of smeared events
  - Compare the E_T^{miss} distribution of the smeared events with the E_T^{miss} distribution of all jet data in the low E_T^{miss} region
  - Vary the Gaussian parametrisation and repeat the above two steps to find the closest match and therefore the optimal Gaussian fit

  - Still need to measure the non-Gaussian part… (see next page)

Jet Smearing – Non-Gaussian Part

- Generate the **non-Gaussian** response function with multi-jet events (preferably Mercedes-like events) where exactly one jet 'J' is parallel to the E_T^{miss}
  - Response of the calorimeter to jet J, if its p_T lies in the non-Gaussian tail, can be obtained from:

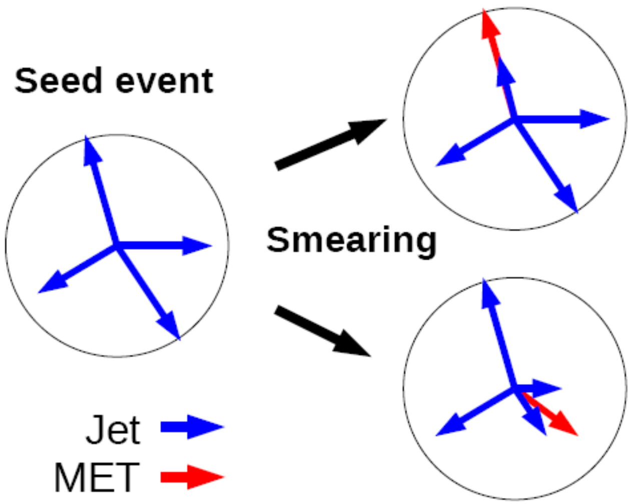
$$R_2 = \frac{p_T^{J} \cdot p_T^{J,true}}{\left| p_T^{J,true} \right|^2} \quad \text{with} \quad p_T^{J,true} \approx p_T^{J} + p_T^{miss}$$



Jet Smearing – Full Jet Response

- Construct full jet response by approximately normalising the Gaussian and the non-Gaussian components
- Derive the normalisation by comparing the measured non-Gaussian response with the tail of the dijet balance distribution
- Use the full response function to 'smear' the four-momenta of jets in events with low E_T^{miss}

→ The smeared jets can now have sufficient E_T^{miss} to enter the SUSY signal region and hence provide an estimation of the multijet background in this region



Jet Smearing

- From SUS-11-04

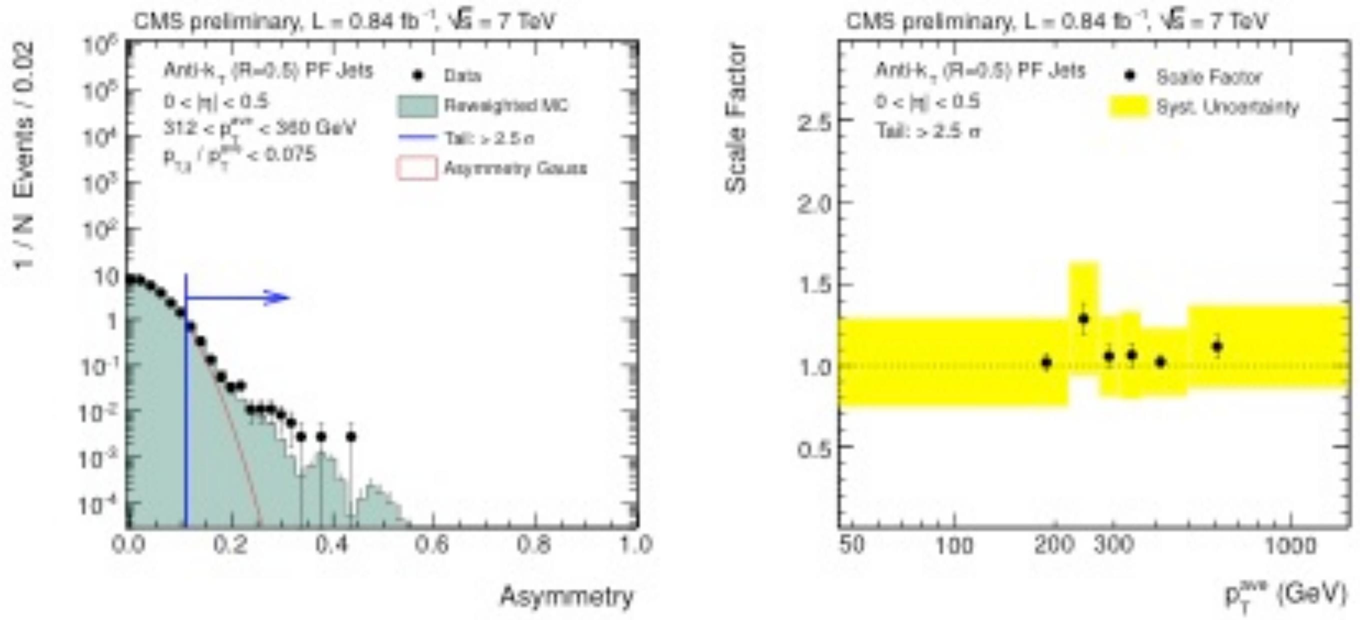


Figure 8: (Left) Example di-jet asymmetry distribution for data (solid circles) compared to the Monte Carlo simulation (filled histogram). The latter has been corrected for the measured core resolution differences. The area beyond asymmetries of 0.1, indicated by the arrow, defines the tail region. For comparison, the hatched area shows number of events expected for a purely Gaussian response. (Right) Ratios of the fractional number of tail events in data and MC simulation in bins of p_T^{ave} for the central η region. They were used as scale factors for the tails of the MC truth response distribution.

Background for prompt Leptons

If SUSY events contain leptons they are prompt!

- Different sources of background leptons possible:
  - Non-prompt leptons from semileptonic heavy quark decays
- For Muons:
  - Decay of long living kaons and pions
  - Calorimeter punchthrough (to muon chambers)
- For Electrons:
  - Jets mimicking electrons
  - Photon conversions in tracker

Lepton Isolation Predictions

- SUSY (and EW) leptons are prompt → should be isolated
- Check e.g. the combined relative isolation (with $\Delta R = \sqrt{\Delta\eta^2+\Delta\phi^2}$)

$$\mathrm{Isolation} = \sum_{\Delta R<0.3} E_T^{\mathrm{ECAL}} \Big/ E_T^{\mathrm{lepton}} + \sum_{\Delta R<0.3} E_T^{\mathrm{HCAL}} \Big/ E_T^{\mathrm{lepton}} + \sum_{\Delta R<0.3} p_T^{\mathrm{track}} \Big/ p_T^{\mathrm{lepton}}$$

Attention: Sums in Isolation exclude the energy and momentum of the investigated lepton

→ Expect value close to 0 (essentially <0.1) for isolated leptons

→ Background mainly >0.3

Try it yourself! These numbers are just examples, and you could also use single isolation for each detector component

But Attention:

EW background ($W \rightarrow l\nu$) is located in SUSY signal region!

Lepton Background Predictions using Fit and Extrapolation for Isolation

- Using the combined relative isolation described before:
  - SUSY signal and EW decays are mainly in Isolation<0.15
  - Background more or less in region Isolation>0.3
- Idea: produce background enhanced sample and fit this in the background region
  - Test different fits/fit regions etc. on this sample (e.g. for small E_T^{miss})
  - Then apply the best fit to data which could contain a signal (e.g. for large E_T^{miss})
  - From this fit predict the number of background events in signal region
- Or use templates:
  - Instead of fit use directly a template data sample (extracted by anti-selection)